NATIONAL AERONAUTICS and
SPACE ADMINISTRATION (NASA)

RELIABILITY CENTERED BUILDING AND EQUIPMENT ACCEPTANCE GUIDE

June, 2000

Preface

The purpose of this *NASA Reliability Centered Building and Equipment Acceptance Guide* is to serve as a technical reference for design engineers, project and program managers, construction managers and inspectors, quality control personnel, and NASA quality assurance staff to use prior to and during the equipment start-up/check-out phase of new construction, repair or rehabilitation projects.

This Guide focuses on the use of Predictive Testing and Inspection (PT&I) technologies by the contractor to detect latent manufacturing and installation defects as a normal part of the contractor's quality control program. Using PT&I for this purpose should not be treated as a separate bid line item nor appreciably increase the project cost.

Additionally, this Guide *does not*, nor is it intended to, address all aspects of Traditional and Total Building Commissioning as practiced widely in industry. For these, the user is encouraged to refer to the comprehensive and detailed commissioning guides, criteria and standards, such as those published by the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), for their appropriate applications.

The intent of this Guide is to supplement the commissioning standards already in place and for the user to use the PT&I practices and standards contained herein in conjunction with traditional process parameters to inspect, test and accept facilities and equipment installations prior to the contractor's departure from the site. The expected result is a quality and safe installation, reduced premature failures, and reduced life cycle costs.

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1. Background

1.1 Introduction

During the course of new construction, major repair, or rehabilitation of facilities, it is not unusual to discover installed systems and equipment that contain latent defects due to manufacturing and/or installation practices or do not operate per design. For example, recent experience with new construction at two NASA Centers and a major facility of another Federal Agency revealed that 85 – 100% of the rotating equipment was either misaligned, out-of-balance, or contained defective bearings.

These types of systems or equipment defects result in premature failures which, to preclude unsafe conditions and to ensure reliable mission support, require unbudgeted corrective action by operations and maintenance (O&M) staff. Given today's increased emphasis on safety (Safety is NASA's number one priority.) and tight facilities O&M budgets, NASA Code JX recommends that each contractor employs a systematic reliability centered testing and acceptance process as part of its quality control program. Included is the use of Predictive Testing and Inspection (PT&I) to verify that systems and equipment meet certain acceptance criteria prior to the contractor's departure from the job site of new construction, major repair, or rehabilitation of facility projects. NASA Code JX believes the result will be a facility that is safer and is less costly to maintain. This system and equipment testing to specific reliability centered criteria and acceptance can achieve these results by:

- Ensuring there are no latent factory or installation defects.
- Verifying building systems and equipment performance through functional performance testing
- Providing full documentation and training for the O&M staff to improve their performance.

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1.1.1 Traditional Commissioning

Traditional Commissioning is a programmed series of design and construction documentation and testing activities that are performed specifically to ensure that the finished facility operates as intended.[1] It involves performing random tests and checks on facility systems to ensure that they are properly balanced, functionally operational and comply with the design intent. It systematically checks operating parameters such as pressure, temperature, minimum and maximum air flow, lighting levels, electrical amperage and voltage, torque, fluid volumes, and other thermodynamic measures at key locations as well as balanced conditions to ensure that the facilities operate as intended. It is a method of acceptance testing that, when performed on a random basis at random sampling points, checks to ensure that the outcome indices at those points are in compliance with the outcome requirements stated in the design specification. Traditional commissioning is typically conducted by the designer and/or by an independent commissioning agent. The procedures used emphasize taking readings at key process indices to determine if the installation is operating as intended. They generally do not include the use of PT&I technologies to check for latent manufacturing and installation defects. Even if the installation is in compliance with the design and reflects the proper process parameters at the time of equipment acceptance, these undetected defects may result in premature equipment failure and operational and maintenance headaches due to misalignment, equipment imbalance or similar condition discovered at a later date. The problem then becomes one of many warranty issues, which based on past, typical NASA history, often are inadequately enforced.

1.1.2 Total Building Commissioning

Total Building Commissioning, as it has emerged in the public and private sectors, is a cradle-to-grave systematic process of ensuring that facility systems are planned, designed, installed, tested, and capable of being operated and maintained to perform according to the design intent and the owner's needs. The Total Commissioning process is optimally applied to all phases of a construction project - program planning, design, construction/installation, acceptance and post-acceptance/occupancy. Commissioning team involvement begins at the earliest stages of project planning, where its expertise in such areas as system sizing, code compliance, maintainability, user friendliness, product quality and reliability, ergonomics and projected life cycle costs, is applied to the design. The commissioning staff is also involved in monitoring the quality of the construction in terms of workmanship and specification and code compliance throughout the construction, using Traditional Commissioning tests and inspection procedures for quality assurance and for system acceptance. Finally, the quality team monitors the installed system following acceptance to ensure that there are no latent installation defects or degradation of system performance and operational quality. This rigorous commissioning process is intended to provide the following benefits:

- Ensure that a new facility begins its life with systems at optimal productivity.
- Improve the likelihood that the facility will maintain this level of performance.
- Restore an existing facility to high productivity.
- Ensure that facility renovations and equipment upgrades function as designed.

1.1.3 NASA's Approach to Commissioning

NASA's approach to Commissioning, as presented in this guidebook, is to integrate reliability centered building and equipment acceptance criteria into the Traditional and Total Commissioning processes. NASA recognizes that there can be substantial benefit when

[1] Heinz, John A., *The Building Commissioning Handbook*, The Association of Higher Education Facilities Officers (APPA), Alexandria, VA 1996.

reliability centered testing and acceptance criteria are applied during the acceptance phase of the construction project. Because of (1) NASA's placing safety as a top priority, (2) the current Federal budget process involving project funding from numerous autonomous and non-integratable sources, (3) NASA's emphasis on reducing life-cycle costs within available and limited resources, and (4) the institution of a strong and vibrant Reliability Centered Maintenance (RCM) program already in place agency-wide, NASA, recognizing RCM's substantial and documented strengths and paybacks, supplements its commissioning program with specific reliability centered criteria that must be satisfied prior to NASA's acceptance of the building, system or equipment from the contractor. It recognizes that substantial benefits can be gained during acceptance and as part of the contractor's Quality Control function. By using available predictive testing and inspection (PT&I) technologies combined with thorough baseline and installation/ manufacturer documentation and traditional operational parameters, acceptance testing will reduce premature failures, increase safety and reliability and decrease life cycle costs.

To date, NASA has concentrated on implementing the RCM philosophy and procedures during the facilities and equipment O&M phase. However, many of the problems, safety concerns and associated costs inherited during the O&M phase are the result of project planning and engineering, which historically have ignored facility and equipment maintainability, and of inadequate or non-existent standards and procedures for equipment acceptance. RCM can directly impact each of these. NASA has recently introduced RCM language into its design procurement specifications, known as SPECSINTACT. The focus of this phase, equipment commissioning, is on safety, cost avoidance and increased reliability, by detecting latent manufacturing and installation defects as part of the contractor's quality control program before the contractor leaves the construction site and turns the installation over to the NASA operations and maintenance staff.

1.2 Purpose of Guide

This guide is intended as a technical reference for design engineers, project/program managers, construction managers/inspectors, contractor quality control personnel and NASA quality assurance staff to use prior to and during the equipment start-up/checkout phase of new construction, repair, or rehabilitation projects. The guide presents methods for ensuring that building equipment and systems installed by the contractor have been installed properly and contain no identifiable defects that will shorten the design life of the equipment. The guide focuses on how NASA in-house staff and contractors can use Predictive Testing & Inspection (PT&I) technologies in their Quality Control program to test, accept, and maintain building systems and equipment. PT&I technologies have been used by world-class corporations and Malcolm Baldridge Quality Award winners extensively for acceptance testing and condition monitoring because they reduce costs while improving safety and reliability.

This guide is *not* intended to limit the inspection and acceptance process to the use of PT&I techniques. In addition to the comprehensive and detailed commissioning guides, criteria and standards published by subject matter expert organizations such as the American Society for Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), this guide is designed to complement other NASA documents such as the *Reliability Centered Maintenance Guide for*

Facilities and Collateral Equipment[2] and the *NASA Facilities Maintenance Management Handbook*[3]. For ease of use, information from those documents is included in this guide.

It is also recommended that in conjunction with this guide the user consults other technical and trade publications, such as those issued by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE)[4,5] and the Association of Higher Education Facilities Officer (APPA)[6] , which provide non-PT&I guidance and may be valuable in planning the Center's commissioning program.

This guide has the following three sections:

- An Introduction to Acceptance Tests and PT&I Technologies
- Acceptance Guidelines and Standards for Systems and Equipment
- Sample Contract Clauses

In addition, appendices provide additional information (i.e., Resources (Appendix A), Sources for Referenced Specifications (Appendix B), Sample Acceptance Data Sheets (Appendix C), a listing of applicable SPECSINTACT clauses (Appendix D)) that may be useful for the design, testing, and accepting new systems and equipment, and a Glossary (Appendix E).

1.3 Introduction to Reliability Centered Maintenance

Reliability Centered Maintenance (RCM) is the process that is used to determine the most effective approach to maintenance. It involves identifying the least cost actions that, when taken, will reduce the probability of failure. It seeks the optimal mix of Condition-based actions, other Time- or Cycle-based actions, or a Run-to-failure approach. RCM is an ongoing process that gathers data from operating systems performance and uses this data to improve design and future maintenance. These maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to minimize costs while optimizing facility and equipment operability and efficiency.

The RCM philosophy employs Preventive Maintenance (PM), Predictive Testing and Inspection (PT&I), Run-to-failure, and Proactive Maintenance techniques and approaches in an integrated manner to increase the probability that a machine or component will function in the required manner over its design life cycle. RCM requires that maintenance decisions be based on function requirements supported by sound technical and economic justification. This is especially true for RCM where the consequences of failure can vary dramatically.

The RCM approach takes a life-cycle view of facilities and collateral equipment. A key element in the transition from good design to full operation is the construction and acceptance phase.

[2] *NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment*, first published in 1996 and revised in February 2000, available from NASA HQ Code JX.
[3] NASA NPG 8831.2, *Facilities Maintenance Management Handbook*
[4] *Guideline for Commissioning of HVAC Systems*, ASHRAE Guideline 1-1989, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA, 1989
[5] *The Building Commissioning Process*, ASHRAE Technical Data Bulletin, Volume 9 Number 1, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA, 1989
[6] Heinz, John A., *The Building Commissioning Handbook*, The Association of Higher Education Facilities Officers, Alexandria, VA 1996

This guide builds upon the RCM philosophy and seeks to ensure that facilities and collateral equipment are properly built and installed in order to reduce the probability of premature failure.

1.4 Why Do RCM?

1.4.1 Safety

Per NPD 8700.1, *NASA Policy for Safety and Mission Success*, NASA policy is to "Avoid loss of life, personal injury or illness, property loss or damage, or environmental harm from any of its activities and ensure safe and healthful conditions for persons working at or visiting NASA facilities." By its very features, including analysis, monitoring, taking decisive action on systems before they become problematic, and thorough documentation, RCM is highly supportive of and an integral part of the NASA Safety policy.

1.4.2 Reliability

RCM places great emphasis on improving system and equipment reliability, principally through the documentation and feedback of initial baseline readings, maintenance experience and equipment condition data to facility planners, designers, maintenance managers, craftsmen, and manufacturers. This information is instrumental for continually upgrading the equipment specifications for increased reliability. The increased reliability that comes from RCM leads to fewer equipment failures and, therefore, greater availability for mission support and lower maintenance costs.

1.4.3 Scheduling

The ability of RCM to forecast maintenance requirements, from as early as taking and documenting baseline data during the construction and acceptance phase and then operational data throughout its life, provides time for planning, obtaining replacement parts, and arranging environmental and operating conditions before the maintenance is done. PT&I reduces the unnecessary maintenance performed by a time-scheduled maintenance program which tends to be driven by the minimum “safe” intervals between maintenance tasks.

A principal advantage of RCM is that it obtains the maximum use from equipment. With RCM, equipment replacement is based on equipment condition, not on the calendar. This condition-based approach to maintenance thereby extends the operating life of the facility and its equipment.

1.4.4 Life Cycle Cost

The facilities life cycle is often divided into two broad stages: acquisition (planning, design, and construction) and operations. RCM affects all phases of the acquisition and operations stages to some degree, as shown in Table 1-1.

Decisions made early in the acquisition cycle profoundly affect the life-cycle cost of a facility. Even though expenditures for plant and equipment may occur later during the acquisition process, their cost is committed at an early stage. As shown conceptually in Figure 1-1, planning (including conceptual design) fixes two-thirds of the facility’s overall life-cycle costs. The subsequent design and construction phases determine an additional 29% of the life-cycle cost.

About 95%, then, of the facility cost is determined by the time the facility is accepted and turned over, leaving only about 5% of the life-cycle cost that can be impacted during the O&M phase.

Life-Cycle Phase	Acquisition Implications	Operations Implications
Planning	Requirements Validation Contract Strategy RCM Implementation Policy Funding Estimates Construction Equipment (Collateral/R&D) Labor Training Operations A&E Scope of Work	Requirements Development Modifications Alterations Upgrades A&E Scope of Work Funding Estimates M&O Considerations Annual Cost Labor Spare Parts
Design	A&E Selection Drawings Specifications Acceptance Testing Requirements	A&E Selection Drawings Specifications Acceptance Testing Requirements
Construction	Contractor Selection Mobilization Construction Activation	Contractor Selection Construction Acceptance Testing
Maintenance and Operation (M&O)	Not Applicable	RCM Operations Training/Certification

Table 1-1. RCM Facility Life-Cycle Implications

Thus, the decision to include a facility in an RCM program, including PT&I and condition monitoring, which will have a major impact on its life-cycle cost, should start as early as the planning phase. Ensuring that facilities meet acceptable RCM criteria and obtaining and documenting critical baseline data are extremely important during the construction phase. As RCM decisions are made later in the life cycle, it becomes more difficult to achieve the maximum possible benefit from the RCM program.

1.4.5 Commissioning Effectiveness

The NASA Construction Engineer/ Commissioning Agent needs to know the system's function in quantifiable terms, its failure modes and the consequences of failure in order to know what tests should be performed during commissioning, the appropriate acceptance criteria of those tests, the cost effectiveness of doing those tests and if they should be done at all, and the level of performance that is acceptable to both the Contractor and to NASA. RCM analyses will assist the Construction Engineer/Commissioning Agent in making those determinations.

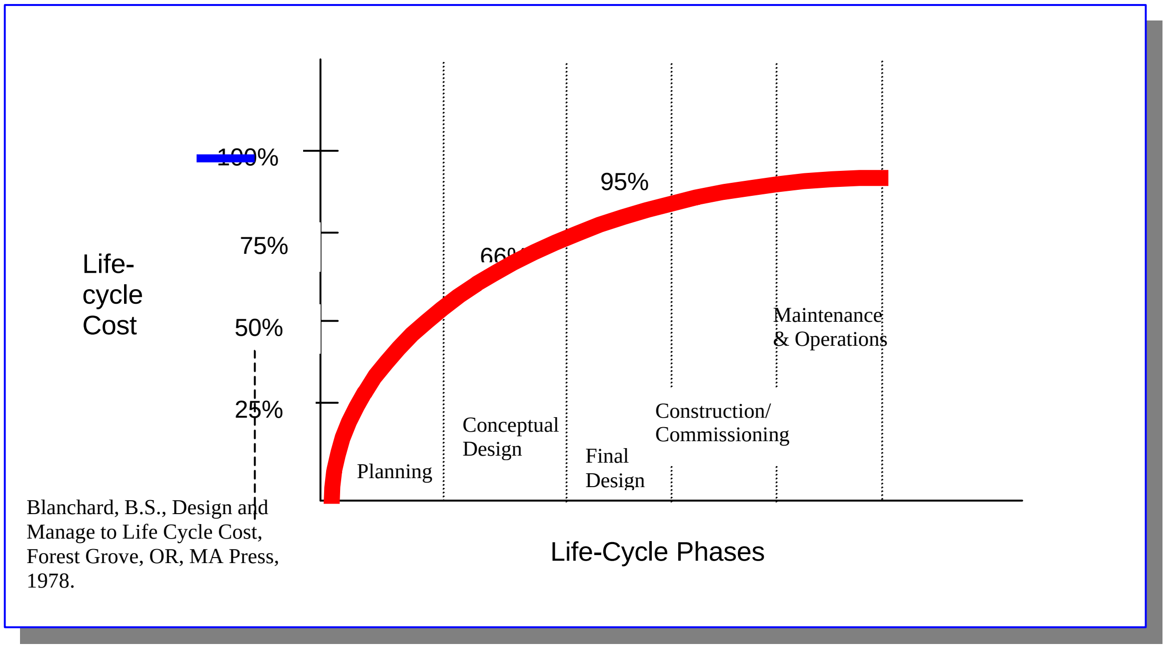

Figure 1-1. Stages of Life-Cycle Cost Commitment[7]

1.5 Responsibilities

1.5.1 Design

The long-term reliability of an installation or refurbishment begins with its initial planning and design. Section 1.4.4 above illustrated that decisions made early in the acquisition cycle profoundly affect the life-cycle cost of a facility with two-thirds[7] of it fixed during the planning and initial design phase. The subsequent design phase determines an additional 29% of the life-cycle cost. Consequently, the project design determines not only the inherent equipment safety, reliability, maintainability, and supportability but the overall cost of the project. The design must then become a functional part of the facility.

NASA has been seeking ways to improve the reliability of its operational facilities and collateral equipment. The RCM philosophy has been integrated into NASA's SPECSINTACT construction guide specifications. That notwithstanding, much emphasis has been placed on selecting the most cost-effective maintenance task to perform including the use of a Condition Monitoring approach when possible. Even so, facilities and collateral equipment reliability is impacted by the ease with which it can be maintained and/or monitored. Therefore, it is important early in the design process to determine what is required to allow for the proper and efficient testing, monitoring, documentation and maintenance to be accomplished. Addressing

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[7] Blanchard, B.S., *Design and Manage to Life Cycle Cost*, Forest Grove OR, MA Press, 1978

safety, accessibility, monitorability, and maintainability in the design process results in the following benefits:

- Maintainability – It has been estimated by NASA facility designers that the cost to make a system change, once the system is built, is anywhere from 10 to 1,000 times more than if the change was made during the system design. Thus retrofitting system maintainability features is often cost prohibitive.
- Improved Reliability – The early performance of PT&I tasks allows for impending failures to be discovered before the functional failure can occur, thus allow the process to be coordinated with the customer and repaired when it is most convenient for the operation. In addition, early failure detection and correction prevents additional collateral damage and the resulting increased repair costs.
- Reduced Life Cycle Cost (LCC) – The result of the above two items is a reduced LCC resulting from reduced O&M costs due to fewer maintenance actions, and increased efficiency of the O&M staff due to improved maintainability.

This Guide can assist the design engineer in identifying the appropriate acceptance testing requirements and include them when they are most cost-effective.

1.5.2 Contractor

The Contractor is responsible for the proper installation of the design or refurbishment requirements as specified in the contract. Acceptance testing using both traditional and PT&I technologies should be performed by the contractor as a part of the QC program throughout the installation process and immediately thereafter to verify that the installation is acceptable and to establish the required baselines. Not until this is complete will the equipment or facility be accepted by NASA for turnover.

In order to accomplish a successful testing program, the contractor performing the work should have an understanding of the NASA RCM process. This guide will assist the contractor in that understanding and define for the contractor what acceptance tests and documentation are required.

Additionally, each contractor shall have a quality control plan outlining the intended methods of receiving, testing, and installing equipment, and how the contractor's work practices contribute to maintaining the design reliability. The contractor must use trained and adequately certified personnel in the appropriate acceptance testing PT&I technologies to ensure that the results are accurate and consistent and must be in possession of the necessary test equipment. As an option, a contractor can retain the services of a subcontractor to whom the requirements of this guide apply.

The contractor shall include in the line item for the proposed Quality Control Plan the cost of furnishing the material requested and the manpower necessary for the operation and maintenance manuals, training, and system verification, as specified.

1.5.3 Construction Manager

During the construction phase, one major concern is the need to monitor the progress and quality of the construction to ensure that the work meets the requirements of the contract documents and is effectively implemented. Throughout this process the Construction Manager oversees the work and acts as the Contracting Officer's representative, approving or disapproving the job, and verifying the required documentation and data are collected.

First, the Construction Manager will verify that the appropriate drawings and documentation are in the possession of the Contractor. Contained in these drawings and documentation should be equipment specifications that include test points meeting PT&I technology and acceptance criteria. It is important that the Construction Manager ensures that the Contractor orders the test equipment as specified, as the design department will have identified the equipment specifically, using the philosophies of RCM and Condition Monitoring.

During construction, the Construction Manager will be responsible for ensuring that any interim testing is performed, the test results meet specifications, are properly documented, and are included with the final acceptance documentation.

Additionally, it is the Construction Manager’s responsibility to ensure that the acceptance testing results are within the required tolerances, and if not, to contact the responsible engineer for direction.

Also, during the construction stage, the Construction Manager should ensure that the appropriate O&M personnel for the system are identified, that training requirements are identified, standard and special operating and maintenance procedures are prepared, safety concerns are addressed, and nameplate and baseline condition monitoring data are collected and documented.

When all acceptance criteria have been met, the final responsibility of the Construction Manager will be to collect all of the required documentation, including all manufacturers manuals, drawing redlines, and all acceptance testing and baseline data, and deliver it to the appropriate O&M personnel.

This guide can help the Construction Manager understand the equipment specifications, what acceptance tests are required, when the testing needs to be performed, and what results are acceptable and what needs to be rejected.

1.5.4 Operations and Maintenance

How the facility and its equipment will be operated and maintained must be considered during the planning, design, and construction phases. During these phases O&M needs are best served by carefully and realistically identifying and defining the PT&I and PM requirements. Although the performance of maintenance and operations occurs during the operations stage of the life cycle, some preparatory activities should be conducted during the construction and acceptance stage. These activities can include personnel selection; planning for the training requirements; procedure preparation; review of specifications, design and nameplate data; review of the *NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment;* and the collection of baseline condition monitoring data from the Construction Manager.

1.6 Reliability Centered Facilities and Equipment Acceptance Intent

The intent of reliability centered facilities and equipment acceptance is to assure the delivery of systems to NASA that are fully functioning in accordance with all specifications and which NASA personnel are fully trained and equipped to operate, maintain and troubleshoot.

1.6.1 Minimum Requirements.

This guide provides minimum program requirements. However, the Contractor shall exceed those requirements whenever it is necessary to achieve the intent of reliability centered acceptance.

1.6.2 Applicable Acceptance Definitions.

Distribution Completion: The stage of the work where the distribution piping and ductwork have been installed and tested, but has not been insulated or concealed by further work.

Equipment Placement Completion: The stage of the work where the major items of equipment have been placed in their final locations but have not received ductwork, piping and electrical connections. "Major equipment" includes, but is not limited to, electrical distribution, heating and cooling plant equipment, dehumidification units, air-handling units, cooling towers, roofing/building envelopes, compressed gas/vacuum systems, and water distribution systems.

Maintenance Orientation and Inspection: At prescribed times during the work, the Contractor will walk the Owner's maintenance personnel through the work, orient them to equipment types and locations, assist access for any requested inspections, and answer all questions concerning the work performance, workmanship standards and quality control. Prescribed training events and the submittal of O&M Manuals shall precede the inspection.

O&M Manuals: Operation and Maintenance Manuals, as specified in Contract Documents.

Participate: Attend commissioning events and provide technical expertise or knowledge, equipment, measurements and observation needed or requested by the commissioning authority or owner. Provide follow-up analysis, equipment data, design data, or other trade or professional service needed in response to commissioning events.

Scope: The facilities/equipment acceptance scope normally includes, but is not limited to, the items described below:

- Document design intent. Verify that equipment and systems have been properly installed in accordance with the contract documents and the manufacturer's written installation instructions.
- Verify that equipment has been placed into operation with the manufacturer's observation and approval.
- Verify that adjusting, balancing and system PT&I testing has been properly performed and that the required PT&I criteria have been satisfied and documented.
- Document all baseline data and ensure it is provided to the appropriate maintenance organization.
- Assemble record drawings.
- Assemble operation and maintenance instructions and submittal data.
- Verify the performance of each piece of equipment and each system.

- Train appropriate NASA personnel in the proper operation and maintenance of each piece of equipment and each system.
- Document the warranty start and end dates.
- Assemble all records of Code authority inspections and approvals.
- Monitor and enforce the accessibility of all work relative to the maintenance requirements of each piece of equipment.
- Identify, document and report all deficiencies of the work relative to the contract documents for tracking and correction through any deficiency tracking program.

TAB: Testing, adjusting and flow balance equipment, as specified in Contract Documents.

Trade Representative: The person who competently represents the work force engaged by the contractor for the individual trade named. This person shall be completely familiar with the work performed for this contract at all levels of detail for the affected trade and as coordinated with the other trades. This person shall be capable of and have authority to execute all commissioning responsibilities of the trade as described in these contract documents.

Verify: Positively determine that the measured or observed quantity satisfies all required criteria. Simply performing the test, measurement or observation does not constitute "verification". The test result must also pass all contract criteria. Tests that fail must be repeated at no additional cost to NASA after repairs or adjustments are made, until full verification is achieved.

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2. Acceptance Testing

2.1 What is Acceptance Testing

After construction is complete it is important to verify that the installation has been properly installed and that the equipment is operating within the desired specifications. Traditionally, the commissioning process does this by verifying system functionality and integrated building performance. During this traditional process, individual equipment and systems are tested for acceptance. These tests tend to focus on thermodynamic performance such as: verifying torque, pressure, flow, temperature, power consumption, direction, and other operational parameters. However, technological advances in recent years allow additional testing for mechanical integrity and component performance such as: vibration, alignment, balance, structural resonance, electrical impedance, and system leakage. These PT&I tests have become one of the most effective methods for testing new and in–service equipment for hidden defects.

The use of PT&I tests for the acceptance of equipment allows the Contractor, as part of the QC program, to verify that the equipment is installed as intended by the NASA design and as specified to the Original Equipment Manufacturer (OEM). Comparison of factory acceptance test results with post installation test results ensures that the equipment was not damaged during transportation or installation and allows for the baseline data to be recorded for future trending and RCM analysis.

The PT&I approaches identified in this guide are in addition to the traditional construction inspection and acceptance criteria. A complete commissioning program should include a combination of PT&I tests and standard performance functionality tests. The remainder of this section describes both types of tests and Chapter 3 describes the combinations used on various types of equipment. Appendices A and B list sources for additional information on the technologies addressed.

2.2 PT&I Technologies

Predictive Testing and Inspection (PT&I) is the use of advanced technology to assess machinery condition. In commercial industry, PT&I is also known as Condition Monitoring or Predictive Maintenance. Work that is done as a result of PT&I data analysis is often called Condition-Based Maintenance. The PT&I data obtained allows for planning and scheduling preventive maintenance or repairs in advance of failure. However, for PT&I data to be effective initial baseline data, normally taken at inception, is needed for comparisons and trending.

Only imagination and money limit the range and use of potential PT&I technologies. In humans, the fields of medicine and bioengineering are continuously developing ways to non-intrusively monitor the body and detect the onset of problems. Likewise, the machinery monitoring field is continuing to grow as new and cheaper technologies are developed. The technologies identified in this guide are not the only technologies available; however, they provide the most cost-effective approach for NASA facilities and collateral equipment. In addition, this section also identifies tests that are used as a one-time, go/no go inspection, such as high potential testing of a motor.

2.2.1 Vibration Monitoring

Vibration monitoring and analysis is the most common PT&I test used by NASA facilities maintenance organizations and by industry. The technique involves examining the vibration signature, either the frequency spectrum or time wave, to identify equipment conditions.

The technique measures machinery movement (vibration) through the use of an accelerometer for facilities equipment with roller element bearings and with a proximity probe for large equipment with journal bearings. In either case, the vibration spectrum is analyzed to identify and trend frequencies related to the electrical and mechanical components of interest. These frequencies, known as "forcing frequencies", are associated with the machine design, regardless of its condition. The amplitude of the forcing frequency determines the condition or severity of the defect. For example, a healthy fan or rotary compressor may have a frequency that is equal to the machine speed times the number of fan blades. The vibration analysts may monitor this frequency to note changes in the amplitude, indicating a degrading or changing condition. Other frequencies, such as those associated with rolling element bearings, may be a sign of bearing damage and will alert the analysts to the start of bearing failure. It is common for electric motor problems, such as broken rotor bars or stator eccentricity, to be seen in vibration signatures associated with electrical line frequency. In new equipment, vibration analysis can identify defective bearings and confirm proper alignment and balance at installation.

Vibration acceptance is used to verify balance and alignment. To help the reader appreciate the significance of vibration acceptance, the following example is provided. At one Federal installation, typical of the Federal Government and consistent with findings within NASA:

- All HVAC pumps were misaligned at installation;
- All HVAC pumps had inadequate shims;
- 90% of the HVAC fans had improper sheaves specified and installed;
- 80% of all fans tested had excessive vibration;
- All fan vibration problems were traceable to balance and/or sheave problems;
- 2 out of 3 vertical pumps had extreme vibration caused by imbalance.

Figure 2-1 illustrates the effect that balance has on the life of bearings. Figures 2-2 and 2-3 illustrate the vibration data from this same Federal installation before and after each system was properly balanced. Had vibration acceptance not been performed, the likelihood that the imbalance would have been detected prior to the occurrence of significant damage and/or a premature failure is slight. The impact that vibration acceptance and continued vibration monitoring during the O&M phase have on the life cycle cost and reliability of the systems is evident.

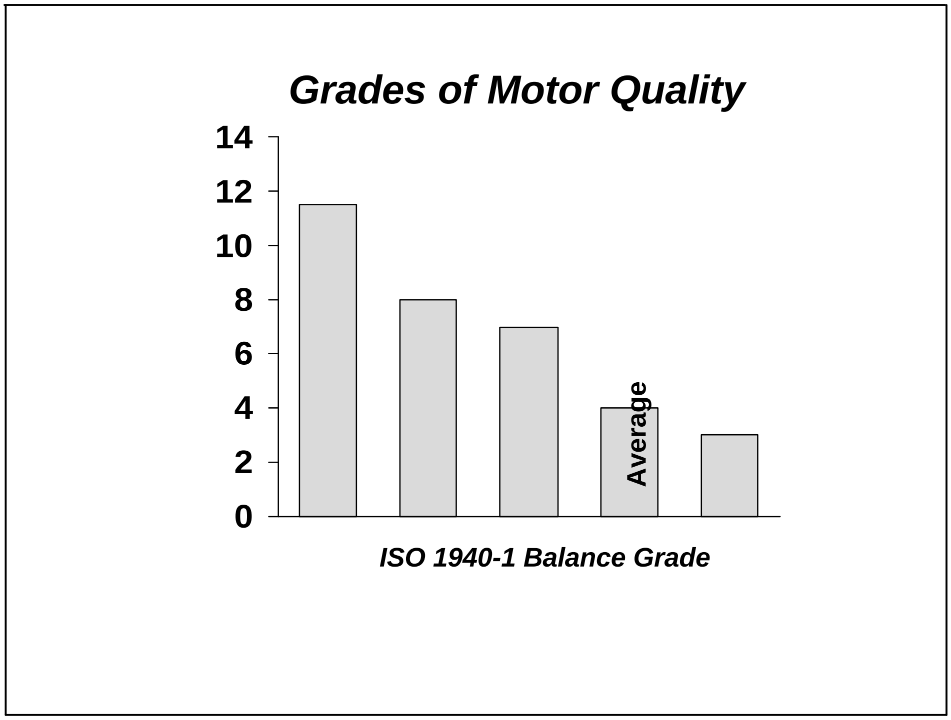


Figure 2-1. Effect of Balance on Bearing Life[8]

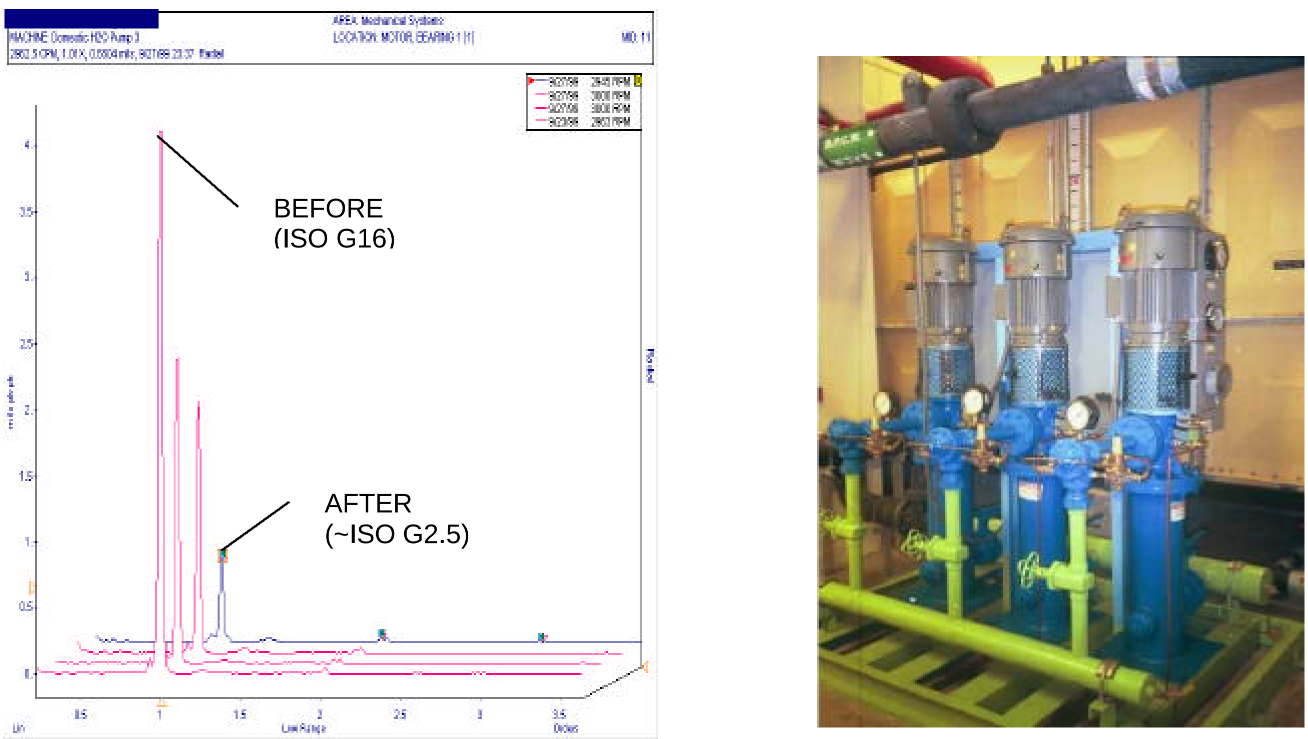


Figure 2-2. Pump Vibration of Domestic H2O Pumps Before and After Balance.

[8] Source: "Balanced Parts, Waking to Reality", SMRP Winter Newsletter, M.Span, Champion International, Pensacola, FL

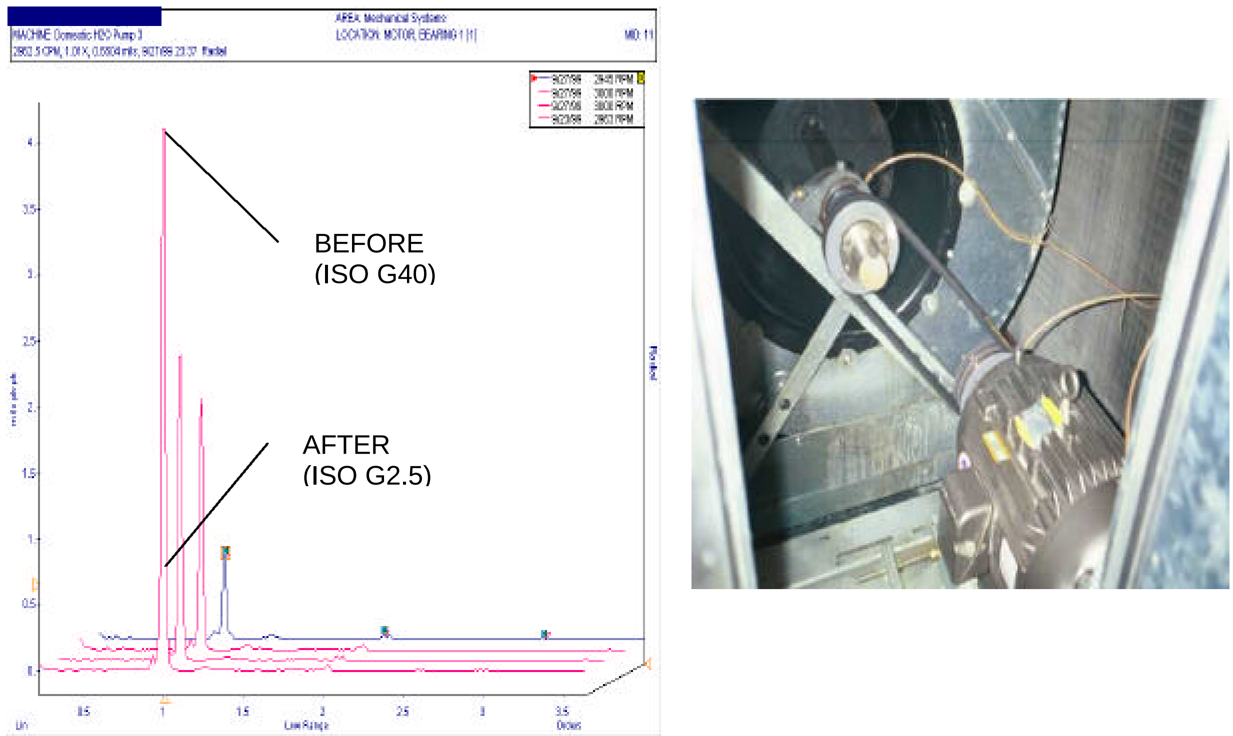


Figure 2-3. Fan Vibration Before and After Balance.

2.2.2 Infrared Thermography (IRT)

Infrared Thermography (IRT) is the application of infrared detection instruments to identify pictures of temperature differences (thermogram). The test instruments used are non-contact, line-of-sight, thermal measurement and imaging systems. Because IRT is a non-contact technique, it is especially attractive for identifying hot and cold spots in energized electrical equipment, large surface areas such as roofs and building walls, and other areas where stand off temperature measurement is necessary.

IRT inspections are identified as either qualitative or quantitative. The quantitative inspection is interested in the accurate measurement of the temperature of the item of interest. The qualitative inspection identifies relative differences, hot and cold spots, and deviations from normal or expected temperature ranges. Qualitative inspections are significantly less time-consuming than quantitative because the thermographer is not concerned with highly accurate temperature measurement. What the thermographer does identify is highly accurate temperature differences between like components. For example, a typical motor control center will supply three-phase power through a circuit breaker and controller to a motor. Current flow through the three-phase circuit should be uniform, which means that the components within the circuit should have similar temperatures, one to the other. As illustrated in Figure 2-4, any uneven heating (perhaps due to dirty or loose connections) would quickly be identified with the IRT imaging system.

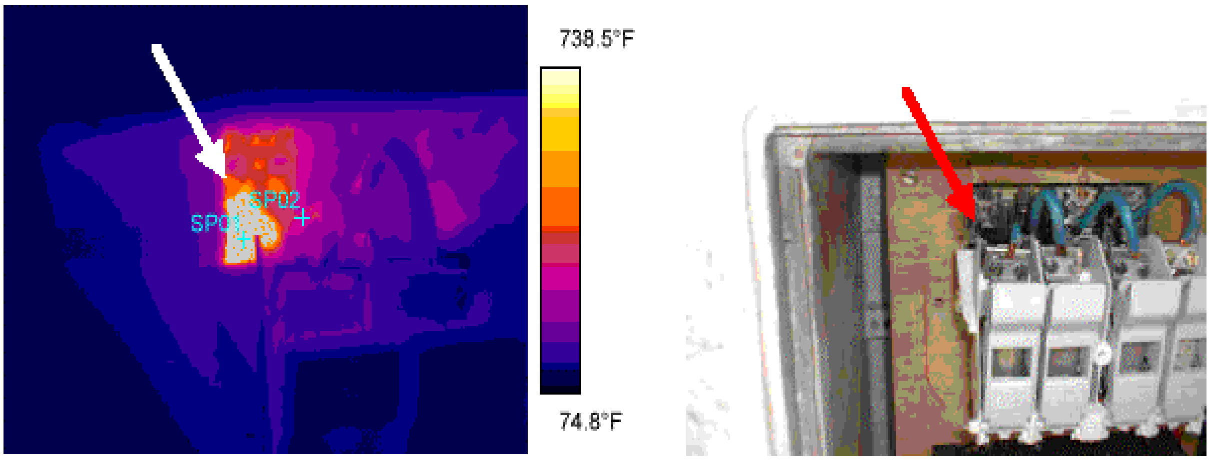


Figure 2-4. Infrared Image of a Bad Electrical Connection at a Major Federal Facility

IRT can be used to identify improper installation conditions in electrical systems such as transformers, motor control centers, switchgear, switchyards, or power lines. In mechanical systems, IRT can identify blocked flow conditions in heat exchanges, condensers, transformer cooling radiators, and pipes. It can also be used to verify the fluid level in large containers, such as fuel storage tanks, and identify improper installation of refractory in boilers and furnaces. Figure 2-5 is an actual infrared image taken at a major Federal installation of a blocked drain pipe under a concrete floor. By looking at the thermal contrast, the Contractor is able to take corrective action while minimizing the excavation area.

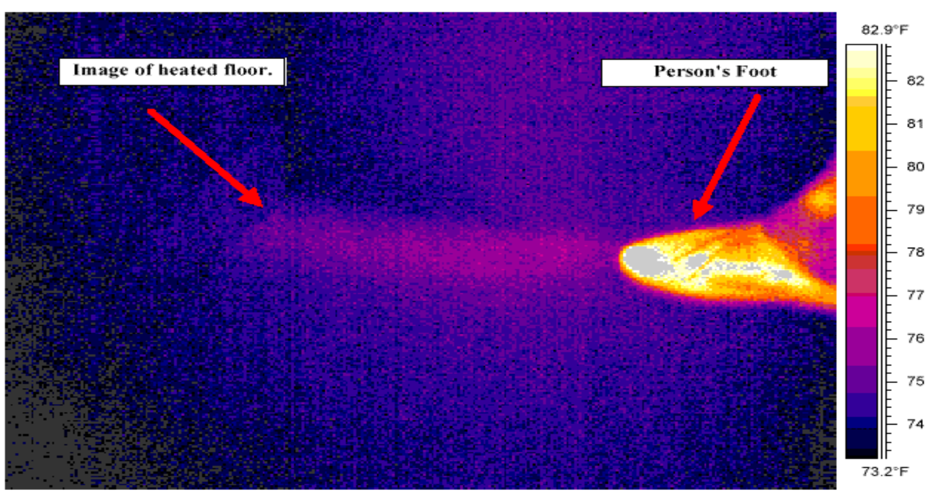


Figure 2-5. Infrared Image of Blocked Drain Pipe Under Concrete Flooring.

2.2.3 Insulation Power Factor

Power Factor, sometimes referred to as "dissipation factor", is the measure of the power loss through an insulation system to ground. The results are expressed in milliwatts loss and percent. The percent refers to a dimensionless ratio, i.e., the percentage of the resistive current flowing through the insulation to the total current flowing. To measure this value, a known voltage is applied to the insulation and the resulting current and current/voltage phase relationship is measured. This test is non-destructive, will not deteriorate or damage insulation, and is recommended for inclusion in any commissioning program.

2.2.4 Airborne Ultrasonic Tests

A relatively inexpensive device called an ultrasonic noise detector can be used to locate liquid and gas (pressure and vacuum) leaks. When a fluid or gas moves from a high-pressure region to a low-pressure region it produces ultrasonic noise, due to turbulent flow. The detector translates the ultrasonic noise to the audible range, allowing an inspector to identify the source of the leak. In addition, an ultrasonic noise detector can detect arcing, tracking, and corona in electrical systems. For electrical systems, ultrasonics are often used in conjunction with the IRT, since corona occurs in the ultraviolet region of the spectrum. Even though this is a subjective test, i.e., results are not quantifiable, it is recommended for use on compressed gas, steam, and vacuum systems as well as on high voltage electrical components.

2.2.5 Dissolved Gas Analysis (Gas-in-Oil)

The oil is analyzed for dissolved gases using gas chromatography. The results can reveal many problems internal to oil filled transformers before the problem becomes terminal. As events occur inside a transformer (some of which are normal), gases are liberated into the oil. Specifically, the primary causes of these gases are thermal, mechanical, and electrical stresses in the windings. Consequently, it is important that new oil has a good baseline with no contaminants, especially combustible gases. This test requires drawing a 50cc sample of oil from the transformer using specialized sampling equipment. Dissolved Gas Analysis is recommended for all oil filled transformers.

2.2.6 Insulating Oil Tests

Similar to lubricating oil analysis, testing is done to confirm that the specified oil is installed and is free from contamination and/or degradation. The tests include Color, Karl Fischer (water in oil), Acidity level (Neutralization Number), Power Factor, Interfacial Tension, and Electrical Dielectric.

2.2.7 Lubricating and Hydraulic Oil Tests

For new facilities and collateral equipment, oil analysis will confirm that the specified lubricants are being used and that the system is free of construction and other contamination. Figure 2-6 illustrates the effects that hydraulic oil contamination has on life expectancy of a machine.

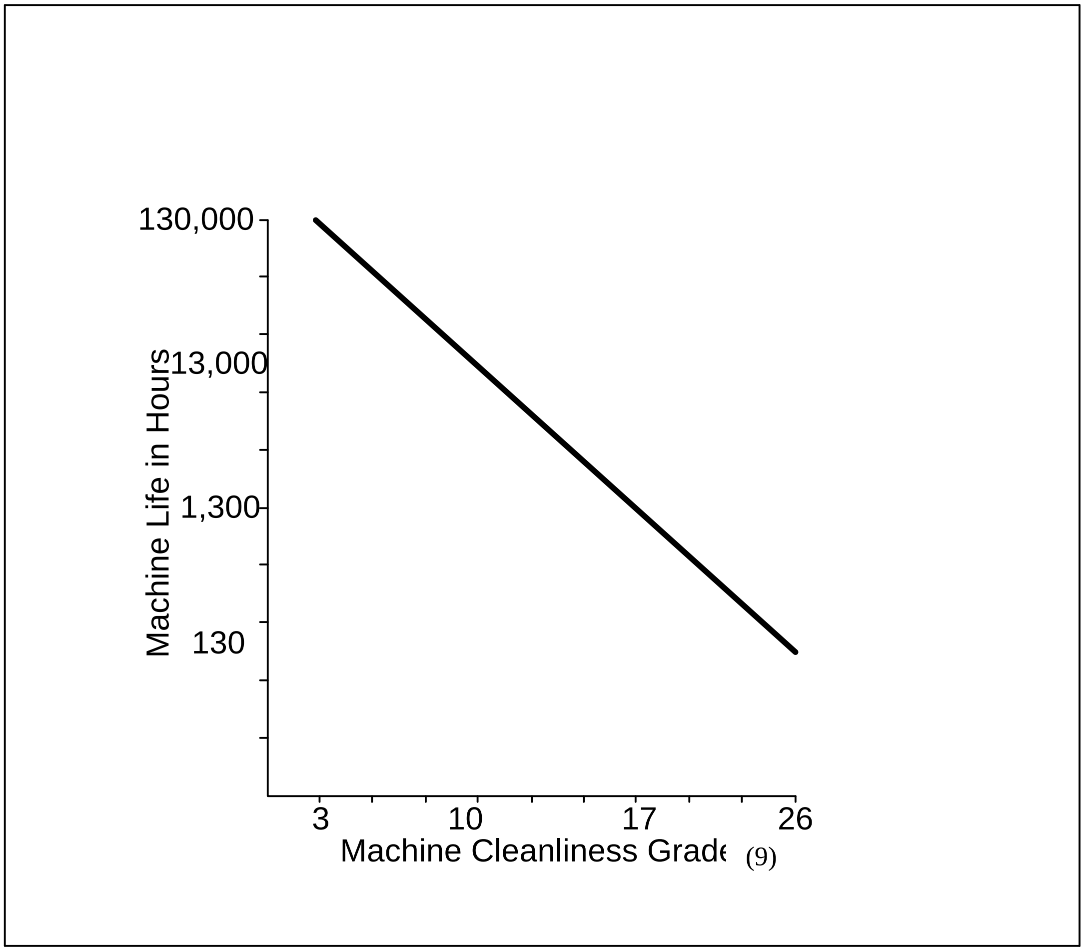


Figure 2-6. The Effect of Hydraulic System Contamination[9]

ISO 4406 establishes the relationship between particle counts and cleanliness in hydraulic fluids (although by common practice this has been extended to other lubricants). The ISO 4406 codes are provided in Table 2-1. Codes are written in either 2- or 3-parts. The 2-part code refers to particle counts in the 5 and 15 micron size ranges, while the 3-part code refers to particle counts in the 2, 5 and 15 micon size ranges. For example, the ISO code 16/13 indicates that in one mL of lubricant there are between 32 - 640 particles greater than 5 microns and between 40 - 80 particles greater than 15 microns. The ISO code 17/14/12 indicates that the sample has between 640 - 1300 particles greater than 2 microns, 80 - 160 particles greater than 5 microns and 20 - 40 particles greater than 15 microns.

[9] "Extending Hydraulic Component Life at Alumax of South Carolina", J. Mayo and D. Troyer, *Reliability Magazine*, Jan 1995

ISO CODE	MINIMUM*	MAXIMUM*
-	-	-
10	5	10
11	10	20
12	20	40
13	40	80
14	80	160
15	160	320
16	320	640
17	640	1300
18	1300	2500
19	2500	5000
20	5000	10000
21	10000	20000
22	20000	40000
23	40000	80000
-	-	-
		* Particles per mL

Table 2-1. ISO 4406 Fluid Cleanliness Codes

Studies of "new" turbine oils, crankcase oils, hydraulic oils, hydraulic fluids and bearing oils delivered to customers indicate varying degrees of cleanliness, with ISO codes from a low of 14/11, to a high of 23/20.[10] Drum-delivered products were generally found to be cleaner than bulk-delivered products. Improper storage and handling procedures can contribute additional contamination to the lubricant. When considering Figure 2-6 in light of this information, the need to check the cleanliness of lubricants at the time of facility and equipment acceptance is all the more evident. Table 2-2 provides the typical base cleanliness targets for various mechanical systems.

[10] "Clean Up Your Oil and Keep It Clean!", Dave Whitefield, *Orbit*, 4th Qtr 1999 (A Publication of Bently Nevada Corp)

MACHINE/ELEMENT	ISO TARGET
Roller Bearing	16/14/12
Journal Bearing	17/15/12
Industrial Gearbox	17/15/12
Mobile Gearbox	17/16/13
Diesel Engine	17/16/13
Steam Turbine	18/15/12

Table 2-2. Typical Base Cleanliness Targets

Water is another major factor in lubricant degradation. Depending on the storage and handling practices, it is often detected in the lubricants found in new systems, components and lubricant deliveries. Its adverse effects in oil include:

- Lubricant breakdown, through oxidation and additive precipitation;
- Changes in viscosity, affecting the ability of the lubricant to maintain the film thickness necessary to protect the component;
- Corrosion; and
- Accelerated fatigue of lubricated surfaces.

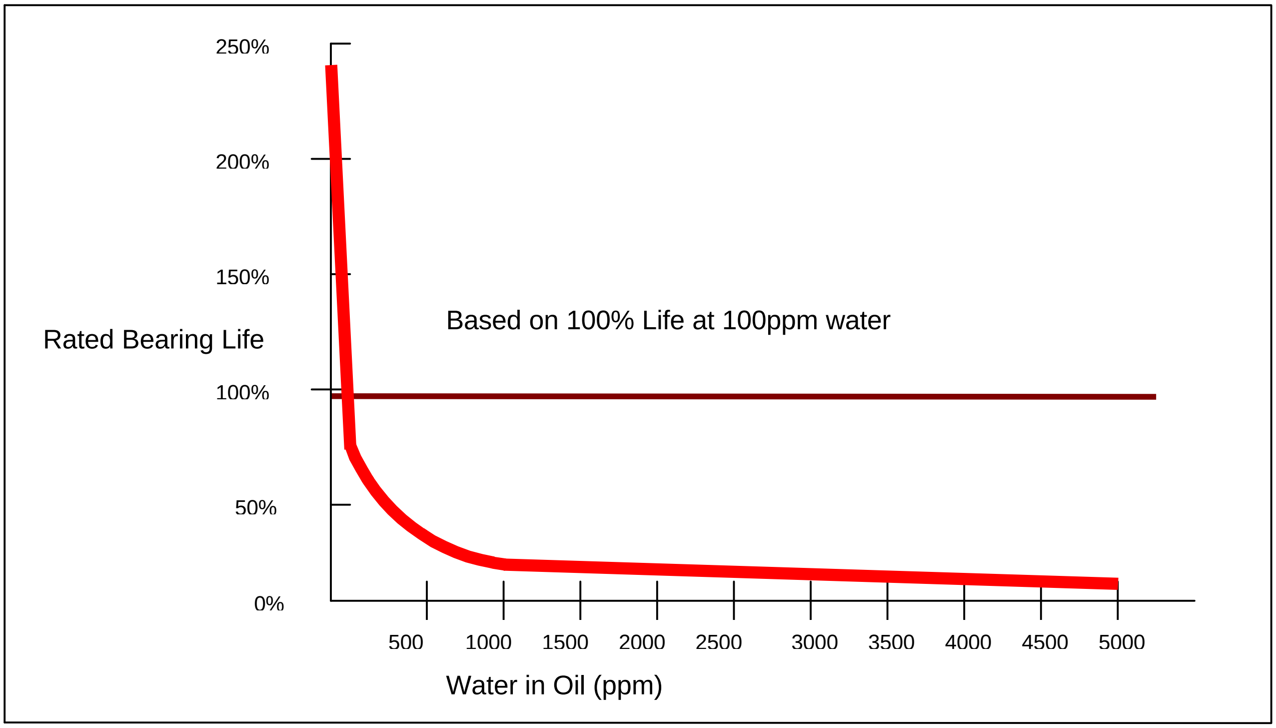


Figure 2-7. Bearing Life Reduction from Water in Oil[10]

The effect that water has on the life of a roller element bearing is shown in Figure 2-7.

In new operating systems, then, lubricating oil analysis is performed for three reasons:

- Determine the machine mechanical wear condition
- Determine the lubricant condition
- Determine if the lubricant has become contaminated.

There are a wide variety of tests that will provide information regarding one or more of these areas. The test used will depend on the test results sensitivity and accuracy, the cost, and the machine construction and application. A comprehensive test will usually monitor the conditions of most interest. At a minimum, testing should be done for:

- Viscosity - Tests oil flow rate at a specified temperature. Viscosity index should also be performed
- Water - Water in lubricating oil and hydraulic fluid can contribute to corrosion, the formation of acids and changes in viscosity.
- Solids - Metallic and non-metallic material contaminants that can lead to premature machinery failure. These Contaminants may result from external contamination (construction, processing, storage and handling debris) or as a result of abnormal, premature wear.

2.2.8 Battery Impedance Tests

A battery impedance test set injects an AC signal between the terminals of the battery. The resulting voltage is measured and the impedance then calculated. This measurement can be accomplished without removing the battery from service since the AC signal is low level and "rides" on top of the DC of the battery. Two comparisons are then made: first, the impedance is compared with the last reading for that battery; and second, the reading is compared with other batteries in the same bank. Each battery should be within 10% of the others and 5% of its' last reading. A reading outside of these values indicates a cell problem or capacity loss. If a battery has an internal short, the impedance tends to go to zero; if an open exists, the impedance will approach infinity.

2.2.9 Insulation Resistance Testing

An Insulation Resistance test is a non-destructive direct current (DC) test used to determine insulation resistance to ground. A DC voltage is applied to the equipment under test, resulting in a small current flow. The test set then calculates the resistance. The insulation resistance is generally accepted as a reliable indication of the presence of contamination or degradation; however, test results vary greatly due to environmental conditions, specifically temperature. Consequently, all readings must be corrected to 20^{o}C for comparisons to be accurate. Under ideal conditions, modern insulation systems can be expected to have life cycles in excess of 100,000 operating hours.[11]

[11] Hodowance and Bezesky, Field Motor Testing: Limiting Risk, IEEE Industry Applications Magazine, May/June 1999

2.2.10 Motor Circuit Analysis

Motor Circuit Analysis is a technology designed to monitor the condition of the complete motor circuit. The test device measures the basic electrical characteristics, conductor phase resistance, conductor phase inductance, and resistance to ground as well as capacitance to ground. The root causes of motor failure in AC three-phase motor stators are frequently found outside the motor.[12] The most common cause is found somewhere after the power supply enters the facility, including (in order of decreasing frequency):

- Distribution transformer defects;
- Uneven loads on individual phases; and
- Deterioration of individual conductor paths.

Checking three-phase motor circuits for resistive balance can be important to assuring long motor operating life. In each three-phase motor circuit the resistance of each conductor path should be as close to equal as possible. Small values of resistive imbalance (up to 2-3%) can be tolerated for short periods without much loss. However, resistive imbalance beyond 5% will begin to reduce life expectancy radically.

Similarly, it is important for inductive balance to be checked. At some point above 15% inductive imbalance, electrically induced mechanical vibrations will occur. When a rotor has a defect, such as broken bars and/or end rings, it has the effect of highly variable imbalance as the rotor position changes relative to the stator windings. During equipment acceptance, the lower the initial imbalance, the longer will be the expected motor life from both electrical and mechanical standpoints.

Motor circuit analysis also evaluates motor circuit capacitance and resistance to ground. The capacitance indicates the amount of dirt and moisture present on the outside of the motor winding insulation, which first, have the effect of helping current "leak" through defective insulation to ground through the motor frame, and second interfere with the motor's designed capability to dissipate heat. From a baseline condition of low capacitance (to ground) this parameter can be trended

Test equipment is portable and computer based, which provides for automated test performance and data collection.

2.2.11 Motor Current Signature Analysis (MCSA)

MCSA detects:

- Broken Rotor Bars
- Defective Shorting Rings
- Rotor Porosity, and
- Air Gap Eccentricity

[12] Jack R. Nicholas Jr., PE, *Motor Circuit and Current Signature Analysis*, AIPE Facilities, July/August 1994

The main indicator of rotor problems is the difference in height, measured in decibels, between the spike at the line frequency and the spike at the pole pass frequency of the motor current signature. (See Figure 2-8.) As the difference decreases, it indicates increased severity of damage to the rotor bars and end rings that make up the rotor cage.

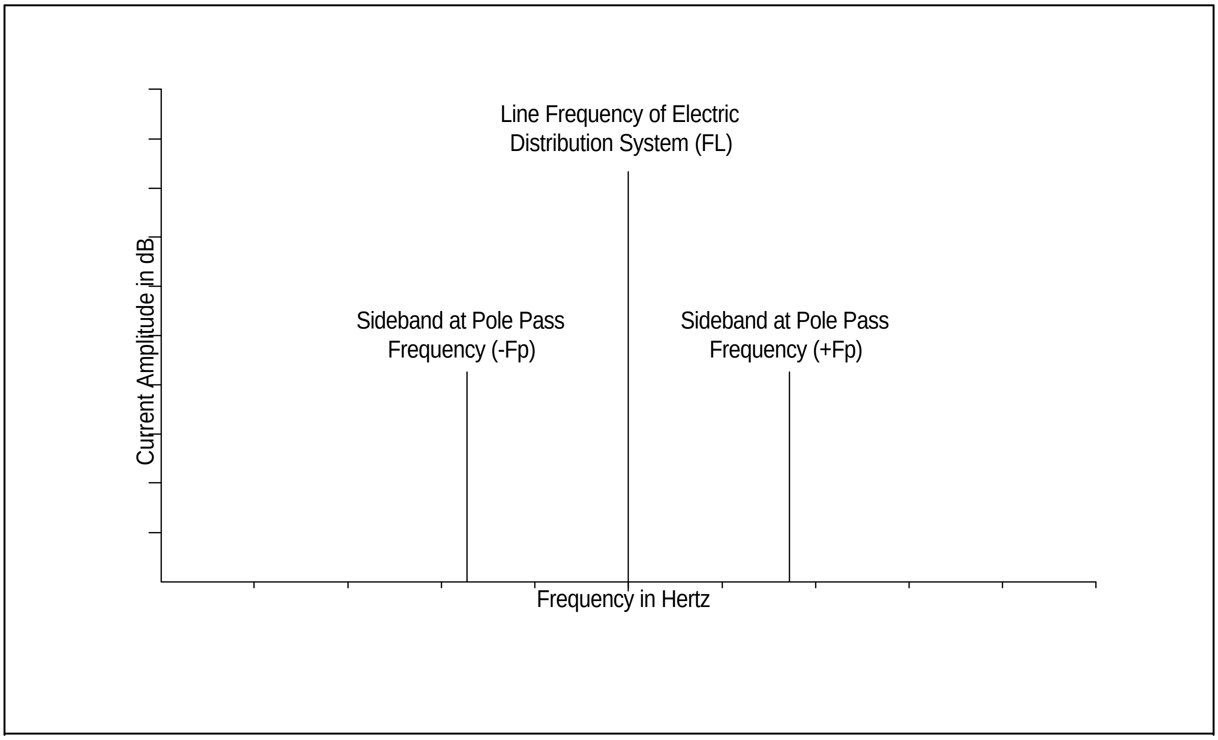


Figure 2-8. Simplified Motor Current Signature

MCSA takes advantage of the fact that an electrical motor is a reliable transducer of mechanically induced loads. Variations in motor load modulate the current flowing through the motor stator windings[13]. These variations in the motor load are due to the non-symmetrical magnetic field in the motor and mechanical feedback due to variations in system response. Spikes are present at or near the one at the pole pass frequency that are induced by other mechanical faults, mainly those in the machinery that the motor is driving. The motor current is filtered to remove line frequency harmonics and transformed to the frequency domain by performing a Fast Fourier Transform (FFT).

2.2.12 Electrical Signal Analysis

Electrical Signature Analysis is an on-line technology where all currents and voltages of a motor circuit are measured, conditioned, and displayed as time domain and frequency spectral data.

[13] Roger Carr, P/PM Technology, Volume 8, Issue 3 – June 1995, p. 50.

The technology allows for the diagnosis of conditions of the power system, motor, and driven component. Data collected includes voltage and current balance, power quality, impedance balance and current sequence data.

2.2.13 Flux Analysis

Flux analysis is a diagnostic technique involving the measurement and analysis of the magnetic leakage flux field around a motor. The technology is designed to detect faults in rotor bars, stator turn to turn shorts, and phase to phase faults. The analysis is similar to that of motor current signature analysis.

2.3 Inspection and Testing Technologies

Inspection and testing technologies are those tests that give results that can be used for acceptance criteria but are not normally used for trending. Most tests in this category can be classified as a go/no-go test, i.e., either the equipment passes or fails the test.

2.3.1 Breaker Timing Tests

A Breaker Timing Test is a mechanical test that shows the speed and position of breaker contacts before, during, and after an operation. There are two general types of timers in use: digital contact timers, and digital contact and breaker travel analyzers. The digital contact timers are only good for timing contacts where no travel time is required. A digital contact and breaker analyzer measures the contact velocity, travel, over-travel, bounce back, and acceleration to determine the condition of the breaker operating mechanism. A voltage is applied to the breaker contacts and a motion transducer is attached to the operating mechanism. The breaker is then cycled (close and open).

2.3.2 High Potential Tests

Hi-Pot testing, illustrated in Figure 2-9, is a high voltage DC test that shows excessive leakage current in equipment. It is also used to verify that insulation systems in new equipment can withstand designed voltage levels. Consequently, it is a good acceptance test for new and repaired electrical transmission and distribution equipment. In repaired equipment, if the leakage current continues to increase at a constant test voltage, this indicates that the repair is not to the proper standard and will probably fail prematurely. For new equipment, if the equipment will not withstand the appropriate test voltage, it indicates that the insulation system or construction method is inadequate for long term service reliability. Since DC Hi-Pot testing is a potentially destructive test, it is a standard acceptance test, especially for new or rewound motors, but normally it is not used for periodic testing.

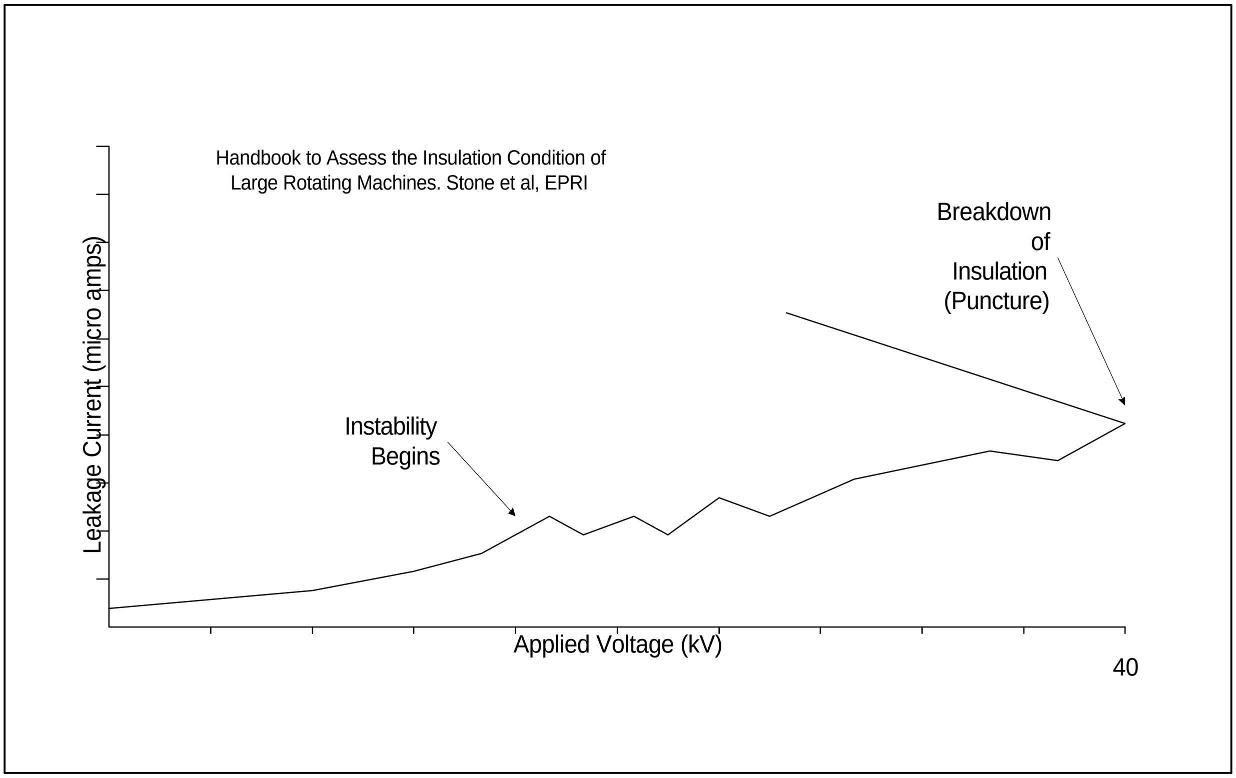


Figure 2-9. Hi-Pot Testing Example

2.3.3 Turns Ratio Tests (TTR)

TTR measures the turns-ratio of a transformer and is mainly used as an acceptance test. It can also be used as a trouble-shooting tool when other electrical tests reveal a possible problem. For acceptance tests, a TTR is performed to identify short-circuited turns, incorrect tap settings, mislabeled terminals, and functional failure in tap changers.

To perform a TTR, a voltage is applied to the primary and the induced voltage on the secondary is measured. The ratio is then calculated and compared to the nameplate data. TTR determines if a fault exists, but does not identify the root cause or the location of the fault.

2.3.4 Partial Discharge (PD) Analysis

Partial Discharge Analysis is an on-line technology designed to monitor the condition of insulation in machines and cables above 4,000VAC. A partial discharge is an incomplete, or partial, electrical discharge that occurs between insulation and either other insulation, or a conductor. These discharges create a high frequency signal that PD monitoring systems are designed to detect. PD typically is performed for very large power generation equipment and large drive units, such as those associated with wind tunnel operations.

2.4 Thermodynamic Performance Tests

Thermodynamic tests are used to verify that systems meet the required levels of functional performance in terms of heating, cooling, utility service delivery and power consumption. These types of tests directly measure pressure, temperature, flow, voltage, current, and power consumption and indirectly measure heat transfer characteristics, system capacity performance, energy efficiency, and control system response.

The performance of thermodynamic tests is essential if system and facility functionality is to be confirmed and base-lined. These types of tests typically use installed sensors, supplemented by temporary sensors, for measuring flow.

2.5 Operational Checks

Operational checks are performed to ensure that systems and facilities respond to changes in demand per design. For example, changes in outside temperature will effect the percentage of make-up air used by the ventilation system. Furthermore, ventilation systems have different operating modes. For example, in a normal operating configuration dampers and supply and exhaust fans will operate in one mode, but during a fire or heavy atmospheric contamination a different mode will be required.

Operational checks test the functionality of the control systems by varying the inputs (i.e., room temperature and humidity) and observing the response of variable speed drives (air handlers and pumps), flow control valves, chiller load, and ventilation dampers.

2.6 Summary

Table 2-3 lists the PT&I technologies that should be used during reliability centered facilities and equipment acceptance, in the order of the greatest to the least expected benefit for the effort expended. Additionally, Figure 3-1 summarizes the most appropriate applications of the PT&I technologies discussed.

PT&I Technology	Expected Benefit
Vibration Analysis	Detects wear, imbalance, misalignment, mechanical looseness, bearing damage, belt flaws, sheave and pully flaws, gear damage, flow turbulence, cavitation, structural resonance, fatigue.
Lubricant and Wear Particle Analysis	Determines machine mechanical wear condition, lubricant condition and if lubricant has become contaminated.
Electrical Condition Monitoring	Detects high resonance connections, phase imbalance and insulation breakdown.
Infrared Thermography	Identifies degrading conditions in transformers, motor control ceneters, switchgear, substations, switchyards, power lines and other facility electrical systems. In mechanical systems, detects blocked flow conditions in heat exchangers, condensers, transformer cooling radiators, and pipes. Can verify fluid levels in large containers and the effects of water and air leaks in roofs and insulation systems.
Ultrasonic Noise Detection	Detects fluid (gas and liquid) leaks and malfunctions (such as faulty steam traps).

Table 2-3. PT&I Technologies In Order of Payback for Facilities and Equipment Acceptance

3. Acceptance Standards

3.1 Overview of Facilities and Collateral Equipment

Facilities contain a myriad of equipment and systems - from the simplest light switch to a computer controlled air conditioning system. While, all equipment can benefit from formal acceptance testing and commissioning in general, it must be understood that even though a reliability centered acceptance test may be available, it is not always cost effective to perform. The determination to perform reliability centered acceptance testing should be based on the RCM philosophy and techniques presented in *the NASA RCM Guide for Facilities and Collateral Equipment* and NPG 8831.2, *The NASA Facilities Maintenance Management Handbook*.

PT&I/Inspection Technology	Motors	Transformers	Breakers	Batteries	Pumps	Diesel Generators	Compressors	Condensers	MCC/Panels/ Switchgear	Roofs/Walls/ Insulation	Heavy Equipment/Craned	HVAC Ducts	Valves	Heat Exchangers	Electrical Systems	Fluid Systems (steam, gas, fluid)	Cables
Vibration Monitoring	●				●	●	●				●						
Infrared Thermography	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	
Insulation Power Factor	●	●	●						●								
Airborne Ultrasonic		●	●		●	●	●	●	●			●	●	●	●	●	
Dissolved Gas Analysis		●	●														
Insulating Oil Tests		●	●														
Lubrication Oil Condition	●				●	●	●				●						
Battery Impedance Tests				●													
Insulation Resistance	●	●	●			●			●						●		●
Motor Analysis(MCE, MCA, MCSA)	●		●						●						●		
Flux Analysis	●	●															
Breaker Timing Tests			●						●								
High Potential Tests	●		●						●								●
Turns Ratio Tests		●															
Partial Discharge Analysis	●	●							●								●
Insulation Resistance	●	●	●						●						●		
Visual Inspection	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Thermodynamic Performance Tests					●		●	●				●	●	●		●	

Figure 3-1. NASA PT&I Technologies

The acceptance tests listed in this section are almost all of the PT&I classification. Again, this does not imply that these are the only acceptance or commissioning tests required. These tests should be used to supplement traditional methods of commissioning and to establish the necessary baselines for a successful Condition Monitoring program. Figure 3-1 is a chart listing the PT&I technologies currently in use by NASA and the equipment that each technology has been or can be applied to.

3.2 Structures

For new structures, the most common concerns after structural integrity are temperature and environment relationships. The desire is for the facility to keep the "outside" out, and the "inside" in. Consequently, because temperature differentials are being investigated, infrared thermography (IRT) is the technology of choice. IRT can be used to locate wet insulation in roofs, insulation voids in walls, and leaks in HVAC systems.

3.2.1 Roofs

Because roofs normally are constructed layer by layer, and because they are comprised of many different types of materials, the inspection of roofs must be a continuous process. Since moisture ingress and contamination is the major failure pattern, moisture must not be allowed to enter the roof structure or materials during the construction phase. Any trapped moisture within the roof system will remain there for the life of the roof. Trapped moisture will eventually degrade the roof and structure and can cause a premature failure of the roofing system.

Traditional roof inspections are usually looking for the *effects* of leaks. IRT instead looks for wet insulation caused by improper installation or roof boundary failures. During the course of a day, the temperature of a roof will increase due to solar loading. However, wet insulation changes temperature at a different (slower) rate than dry insulation, so as the roof cools in the evening there is the opportunity to take advantage of this temperature difference and locate any wet insulation. The reverse process occurs in the morning and offers a similar, but more limited, opportunity to identify a temperature difference.

Roof inspections using IRT typically have a small thermal “window” of opportunity to see this temperature difference. Factors to contend with are winds, dew, and ambient temperature. Eventually, the entire roof surface will reach equilibrium and the IRT inspection from that point becomes ineffective - the “window” is closed until the next temperature swing.

Most moisture problems in new roofs are often due to improper installation (e.g., insulation materials become wet before the layers are sealed) or breeches around flashings and penetrations. Leaks caused by the latter can sometimes be quite a distance away from the actual breech. Different insulation types will produce different IRT images. Some will appear as straight lines, indicating that there is moisture in the seams. Others will appear as puddles with free forming edges due to the wicking of the moisture. Any anomalies found must be turned over to the contract administrator for repair by the roofing contractor. Figure 3-2 is an IRT image of a wet roofing system. The moisture pattern is evident.

3.2.1.1 Built-up Roofs

The first inspection should be a visual one, after all roof penetrations are complete. The inspection should be thorough enough to ensure that there is a good, weatherproof seal on all penetrations and that the surface is free of moisture and contamination before allowing the base layer to be installed.

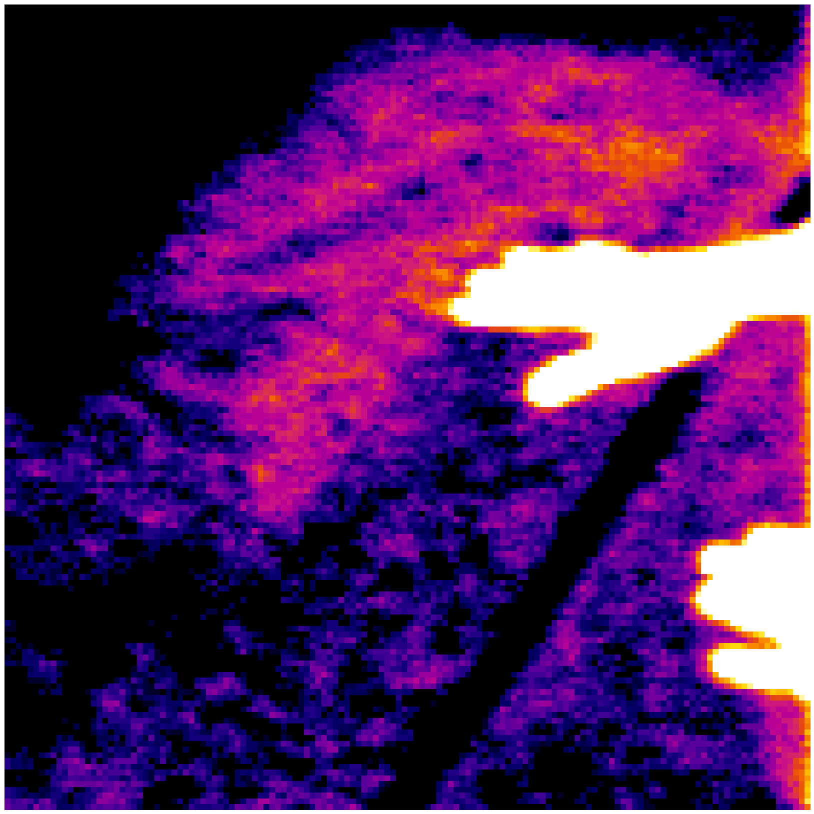


Figure 3-2. Infrared Image of Moisture Under Roof [14]

After the final layers are completed, the entire roof should again be inspected visually. All penetrations and flashing should be watertight at the roof penetration. Additionally, all insulation materials and their locations must be identified and documented for future reference. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

Following a minimum of 90 days operation (or installation), but no later than one year, and having let nature take its course, the appropriate maintenance organization (i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc.) should inspect the installation using advanced monitoring technologies such as IRT or Ultrasonic mapping. Although it is recognized that facility acceptance has already taken place, these technologies can identify insulation voids, insulation settling, and areas of moisture intrusion that could have been

[14] Image provided by Kennedy Space Center (SGS))

overlooked during the initial inspections and for which the contractor is still responsible under the terms of the construction contract warranty.

3.2.1.2 Membrane Roofs

As with built-up roofs, the first inspection should take place after all roof penetrations are complete. The inspection should be thorough enough to ensure that there is a good, weatherproof seal on all penetrations and that the surface is free of moisture and contamination before allowing the base layer to be installed.

After its installation, the outer membrane should be inspected for the proper seam overlap and connection. All penetrations and flashings should be watertight. All insulation materials and their locations must be identified and documented for future reference. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

Following a minimum of 90 days operation (or installation), but no later than one year, and having let nature take its course, the appropriate maintenance organization (i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc.) should inspect the installation using advanced monitoring technologies such as IRT or Ultrasonic mapping. Although it is recognized that facility acceptance has already taken place, these technologies can identify insulation voids, insulation settling, and areas of moisture intrusion that could have been overlooked during the initial inspections and for which the contractor is still responsible under the terms of the construction contract warranty.

3.2.1.3 Metal Roofs

Unlike built-up and membrane roofs, metal roofs have no insulation. They are normally single layer, overlapped corrugated galvanized steel or aluminum sheeting. Consequently, inspections will consist of verifying that the proper material has been used and ensuring that the construction is watertight and properly anchored.

3.2.2 Insulation/Building Envelope

As with roofs, building insulation is installed during construction, but in most cases, prior to the building being completed. Consequently, acceptance inspections of the envelope insulation must occur before the walls and ceilings are completed.

On completion of the insulation installation, a construction detail showing the insulation material type, amount, and location shall be generated and submitted by the contractor. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

Following a minimum of 90 days operation (or installation), but no later than one year, and having let nature take its course, the appropriate maintenance organization (i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc.) should inspect the installation using advanced monitoring technologies such as IRT or Ultrasonic mapping. Although it is recognized that facility acceptance has already taken place, these technologies can identify insulation voids, insulation settling, and areas of moisture intrusion that could have been overlooked during the initial inspections and for which the contractor is still responsible under the terms of the construction contract warranty.

3.2.3 Piping Systems

Industry standard commissioning tests for water, plumbing and air systems first require a pressure test of all piping and fittings. During this test, an ultrasonic scan should be performed on all accessible above ground piping to help discover any leaks. See also Section 3.3.5, *Airborne Ultrasonics*.

For hot water systems, after the standard pressure and hydro tests are completed and after the piping insulation has been installed, the system should be charged with hot water. An infrared scan should then be performed to verify insulation integrity.

For steam systems, ultrasonic scans should be performed on steam traps.

3.3 Mechanical Systems

3.3.1 Vibration Analysis

This section establishes acceptable limits for vibration levels generated by new and rebuilt rotating machinery and equipment, including: standardized measurement axis directions and locations, calibration and performance requirements of the instrumentation, and procedures for reporting vibration data for machine certification and acceptance.

3.3.1.1 Instrumentation Requirements

Vibration measurements will be made with a fast Fourier transform (FFT) analyzer. The type, model, serial number(s), and latest certified calibration date of all equipment used in the measurement of vibration levels for machine certification shall be recorded and made available on request.

The FFT analyzer shall be capable of a line resolution bandwidth Δf = 300 cpm for the frequency range specified for machine certification, unless this restriction would result in less than 400 lines of resolution. In that case, the requirement defaults to 400 lines of resolution. (Higher resolution may be required to resolve "side bands," or in Band 1 to resolve machine vibration between 0.3X and 0.8X running speed.)

The dynamic range shall be a minimum of 72 dB.

The FFT analyzer shall be capable of applying a Hanning window.

The FFT analyzer shall be capable of linear non-overlap averaging.

The FFT analyzer shall have antialiasing filters.

The measurement system (FFT analyzer, cables, transducer, and mounting) used to take vibration measurements for machine certification and acceptance shall have a measurement system amplitude accuracy over the selected frequency range as follows (see Figure 3-3):

- For displacement and velocity measurements, ±l0% or ±1 dB
- For acceleration measurements, ±20% or ±1.5 dB

Figure 3-3 Measurement System Frequency Response.

The vibration equipment (transducer, preamplifier, FFT analyzer, recorder, and connecting cable) used to take vibration measurements for machine certification and acceptance must be calibrated by a qualified instrumentation laboratory in accordance with Sections 5.1 and 5.2 of ANSI S2.17-1980, *Technique of Machinery Vibration Measurement*, within one (1) year prior to use.

The calibration shall be traceable to the National Institute of Standards and Technology (NIST) in accordance with ISO 10012-1/1992, *Quality Assurance Requirements for Measuring Equipment—Part 1: Meteorological Confirmation Systems for Measuring Equipment*.

3.3.1.2 Vibration Transducers

An accelerometer shall be used in the collection of data for machine certification and acceptance. The accelerometer must be selected and attached to the machine in such a way that the minimum frequency (F_{min}) and maximum frequency (F_{max}) are within the usable frequency range of the transducer and can be accurately measured (reference manufacturer recommendations and/or Section 6.3, ANSI S2.17-1980).

The mass of the accelerometer and its mounting shall have minimal influence on the frequency response of the system over the selected measurement range. (A typical mass of accelerometer and mounting should not exceed 10 percent of the dynamic mass of the structure upon which the accelerometer is mounted.)

3.3.1.3 Vibration Measurement Locations

The required measurement positions and orientations on the surface of a machine at which vibration measurements are to be taken shall be determined by mutual agreement between NASA and the contractor, and shall meet the following requirements:

- If an obstruction or safety consideration prevents locating a transducer as specified, locate it as close as possible to the standardized position.
- Measurement locations used for machine certification and acceptance shall be identified on the machine layout drawing and/or physically on the machine, as mutually agreed upon by NASA and the contractor.
- Vibration measurement locations shall be on a rigid member of the machine, as close to each bearing as feasible. Bearing housings, bearing pedestals, machine casings, or permanently mounted pickup mounting blocks are examples of suitable mounting locations.
- The vibration measurement location shall NOT be on a flexible cover or shield, such as the fan cover on an electric motor or a sheet-metal belt guard.
- Any guarding must be designed to allow accessibility to all measurement locations.

If vibration monitoring points are rendered inaccessible after the machine is built or access to the measurement points presents a safety problem during measurement, the NASA Construction Manager shall be contacted to determine if permanently mounted transducers are to be installed.

3.3.1.4 Transducer And Machine Mounting Conditions

In order to monitor motor vibration, the motor housing must have a smooth surface in the vertical, horizontal, and axial directions at each bearing housing, suitable for attaching a magnet-mounted accelerometer. See Figure 3-4 for typical vibration measurement locations. The surface shall be on the bearing housing. The axial surface will be as close to the motor centerline as possible. The surface will have a finish of 63 micro-inch minimum. The diameter of the finished surface shall be 2-inch minimum and must be corrosion resistant.

As an option, sound disks can be used to meet the smooth surface requirement. As illustrated in Figure 3-5, the disk shall have a minimum thickness of 3/8 inch. The disc or surface face must be level to prevent the magnet from rocking and the surface must be level within 1 degree or .001 inch. Good frequency response is more directly related to placing the magnet on a clean surface with a lubricant between the magnet and the disc than on a highly polished disc surface. If an adhesive is used to attach the sound disk, the upper frequency limit of the transducer shall be reduced by 20 percent of the manufacturer’s stated resonance for “hard” adhesives, and by 50 percent of the manufacturer’s stated resonance for “soft” adhesives. The transducer manufacturer’s specifications should be consulted.

For a stud-mounted transducer, the surface of the machine at which vibration measurements are to be taken shall be in accordance with that specified by the transducer manufacturer (torque, grease, etc.). The designated transducer type will be specified by NASA.

3.3.1.5 Machine Certification and Acceptance

The following are the measurement requirements for machine certification. Vibration measurements shall:

- Be the responsibility of the Contractor unless specified otherwise by NASA.

Figure 3-4. Typical Vibration Measurement Locations.

- Be performed by a technically qualified person who is trained and experienced in vibration measurement. The technical qualifications of the person doing the vibration certification shall be submitted as a part of the machine vibration certification data.
- Be taken with the machine operating as specified. Where "no load" is specified, no actual work is to be taking place during collection of machine vibration data. Where

"rated load" is specified, rated operating load, either actual or simulated, will be applied during the collection of machine vibration data.

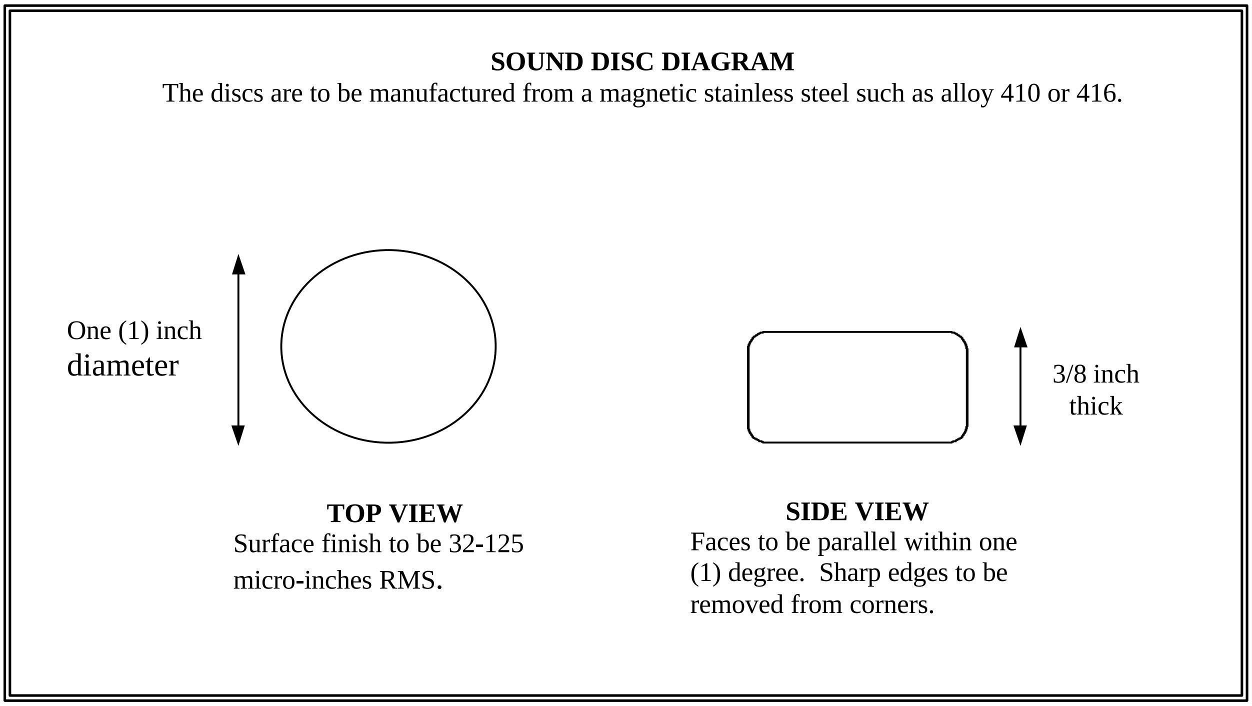


Figure 3-5. Sound Disc Diagram

- Prior to vibration measurements, the machine will be "run in" until it reaches operating speed and thermal stability.
- Vibration signatures shall be submitted to the NASA Construction Manager before the acceptance of the machinery or equipment being purchased will be authorized.
- Narrowband vibration data for machine certification shall be measured during "run off" at the vendor's facility. A baseline or reference spectrum should be provided for comparison with post-installation vibration checks. Equipment failing the vibration criteria should be rejected by the procuring organization prior to shipment. Where it is impractical to set up and test a complete machine at the vendor's facility, arrangements shall be made to perform the test at the NASA Center. Under this circumstance, shipment of the equipment does not relieve the contractor of the responsibility for meeting the specified vibration-level limits.
- NASA will have the option to verify the equipment vibration data during machine "run off" at the vendor's test site prior to shipment or at the NASA Center prior to final acceptance authorization.
- The machine layout drawings shall be submitted as a part of the Machine Vibration Certification. Vibration measurement locations on the surface of the machine at

which vibration measurements are taken shall be designated on the drawing. At NASA's option, shaft speeds (rpm), gear type and number of gear teeth, gear mesh frequencies (cpm), bearing manufacturer's name, and bearing type number and class shall be identified on the machine layout drawing. Where gearboxes are involved, an insert similar to the one illustrated in Figure 3-6 shall be included on the machine layout drawing.

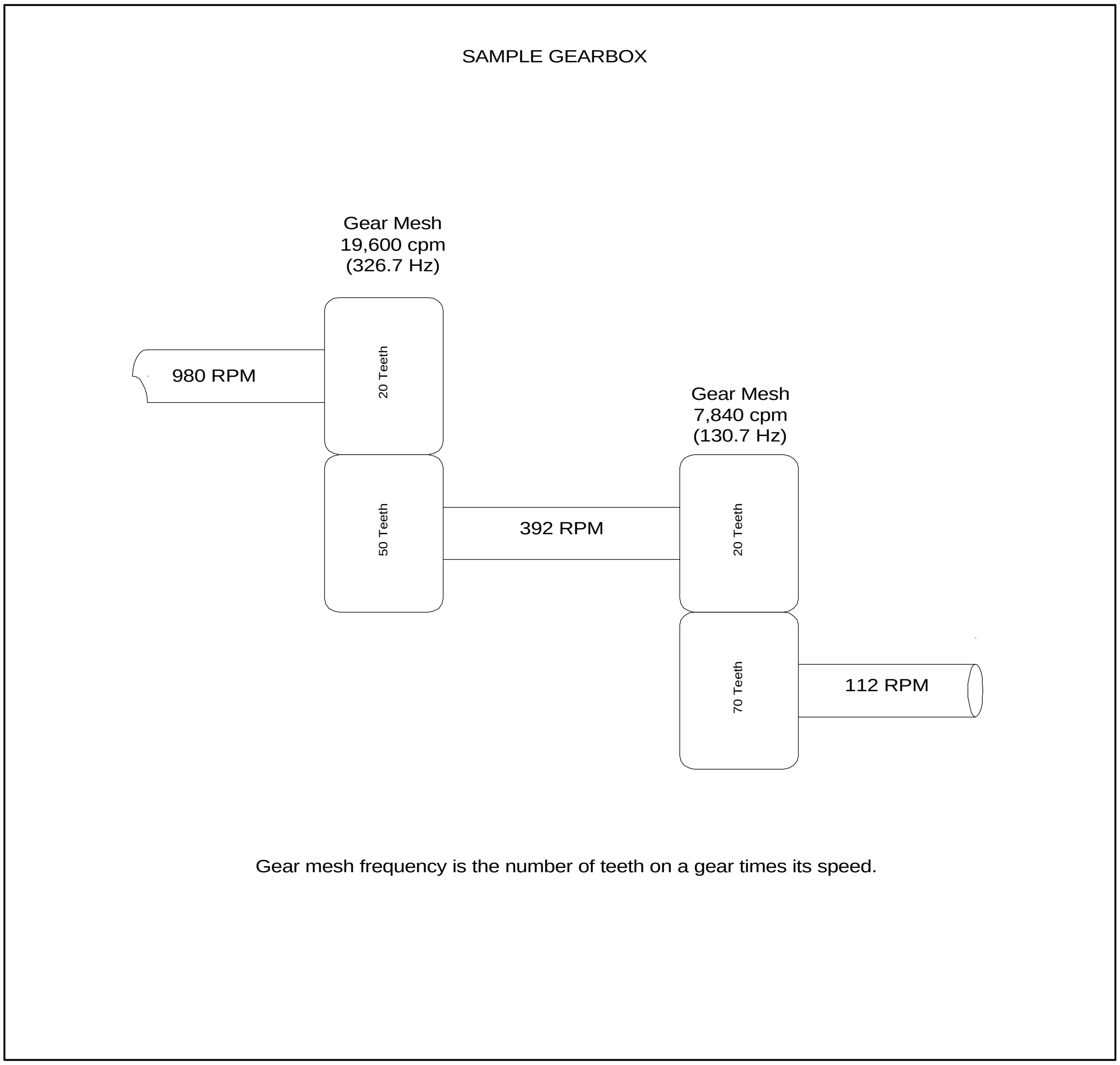


Figure 3-6. Sample Gearbox Diagram

Vibration tests are recommended under the following situations if the equipment fails the initial test and/or if problems are encountered following installation:

- Motor cold and uncoupled.
- Motor hot and uncoupled.
- Motor and machine coupled, unloaded and cold.
- Motor and machine coupled, unloaded and hot.
- Motor and machine coupled, loaded and cold.
- Motor and machine coupled, loaded and hot.

A significant change in the vibration signature under each scenario could indicate a problem with thermal distortion and/or bearing overloading due to the failure of one of the bearings to float.

Authorization for machine and equipment acceptance based on vibration limits requires a signature by the NASA Construction Manager. This information along with all other test documentation should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.1.6 Vibration-Level Limits

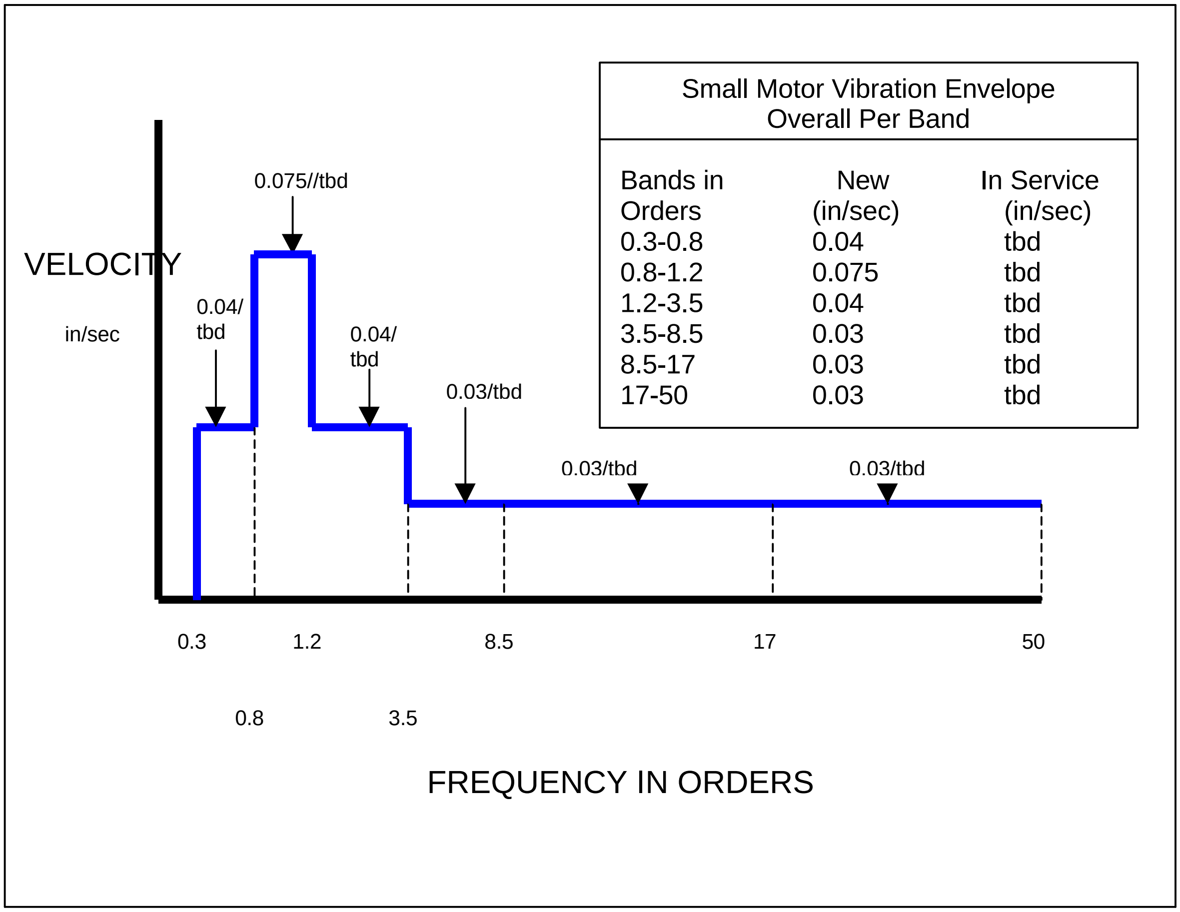
A. Vibration Standards For Electric Motors

Alternating-current motors will be tested at rated voltage and frequency, and no load. Single-speed alternating-current motors will be tested at synchronous speed. A multispeed alternating-current motor will be tested at all of its rated synchronous speeds. Direct-current motors will be tested at their highest rated speed. Series and universal motors will be tested at operating speed.

All electrical motors defined by NEMA Standard MG-1-1993 Section I, *Classification According to Size*, shall meet the following requirements:

- The velocity amplitude (inch/sec-peak) of any line of resolution, measured at bearing locations in any direction shall not exceed the line-amplitude band limit values specified in Figures 3-7 and 3-8 for small and large motors, respectively.
- The acceleration overall amplitude (g's peak) at bearing locations in any direction shall not exceed the band-limited overall amplitude acceptance limit appropriate for the motor being tested.

For electrical motor certification, the amplitude of vibration at bearing locations in any direction shall not exceed the values listed in Figures 3-7 and 3-8 for small and large motors, respectively. Vibration signatures of velocity and acceleration, and a listing of the maximum peak velocity in each band for vibration measurements taken at position 1 horizontal, position 2 vertical, and position 3 axial shall be submitted as part of the motor certification. The data shall be identified with the motor serial number, frame number, model number, horsepower, and synchronous speed.



Small Motor Vibration Envelope
Overall Per Band

Bands in Orders	New (in/sec)	In Service (in/sec)
0.3-0.8	0.04	tbd
0.8-1.2	0.075	tbd
1.2-3.5	0.04	tbd
3.5-8.5	0.03	tbd
8.5-17	0.03	tbd
17-50	0.03	tbd

Figure 3-7. Small Motor Vibration Envelope Overall per Band.

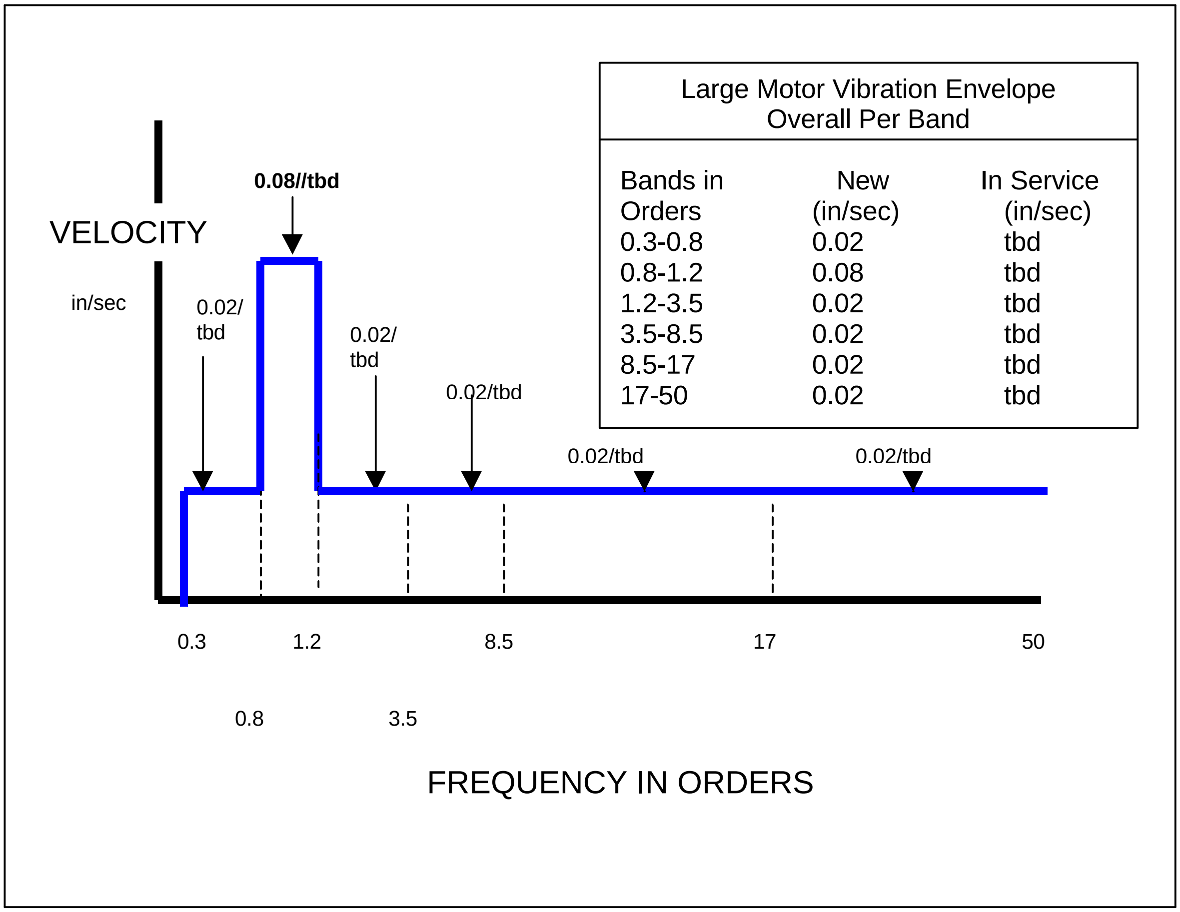


Figure 3-8. Large Motor Vibration Envelope Overall Per Band

B. Vibration Standards for Fans

Fans are defined as all non-positive displacement air handling units, including, but not limited to, induced draft (ID) fans, forced draft (FD) fans, overhung fans, centerhung fans, centrifugal, vaneaxial, tubeaxial, and blowers.

Natural frequencies of the completely assembled fan unit shall not be excited at the operating speed. (Running speed should be at least 25 percent removed from a natural frequency of the system.)

Variable speed or adjustable sheaves shall not be used in the final installation.

The drive sheave and driven sheave should differ in size by 20 percent or more to avoid "beat" vibration.

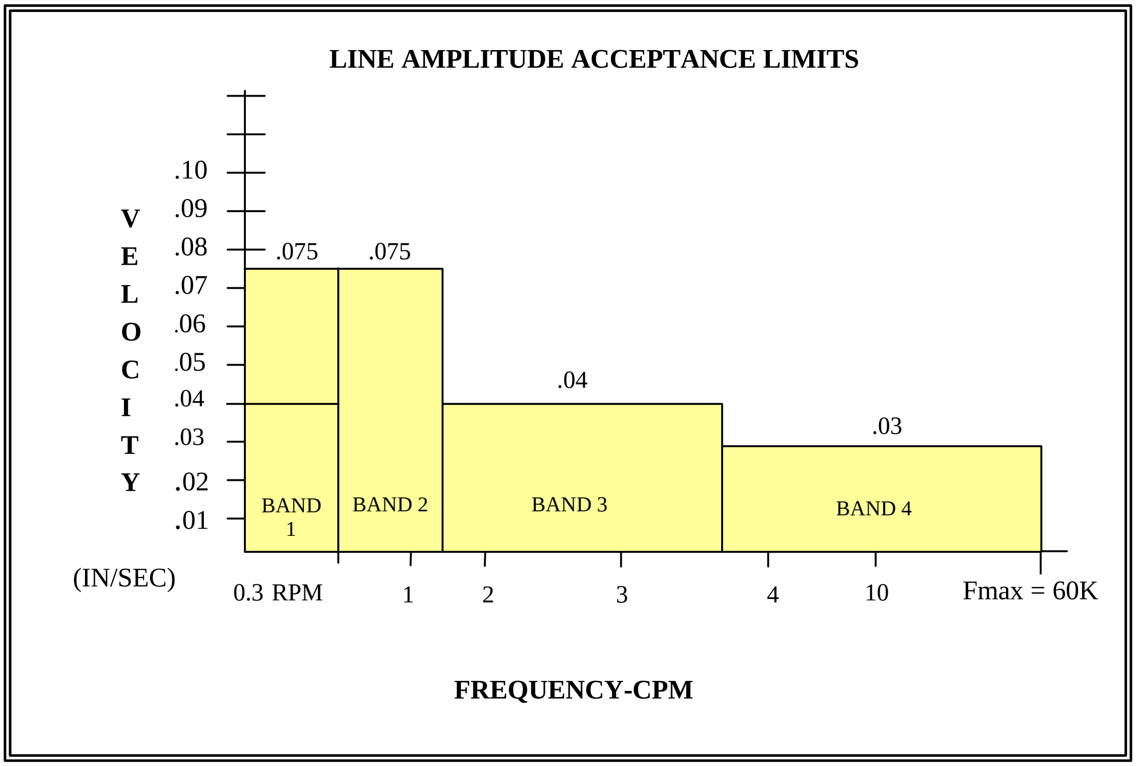


Figure 3-9. Belt Driven Fan Vibration Envelope Overall Per Band

Vibration limits for fans are as follows:

- New, rebuilt and repaired fans shall conform to the vibration limits specified in Figures 3-9 and 3-10 when operating at the specified system volume (cfm) and fan static pressure.
- Acceptance limits for fans running over 3,600 rpm will be specified by NASA.

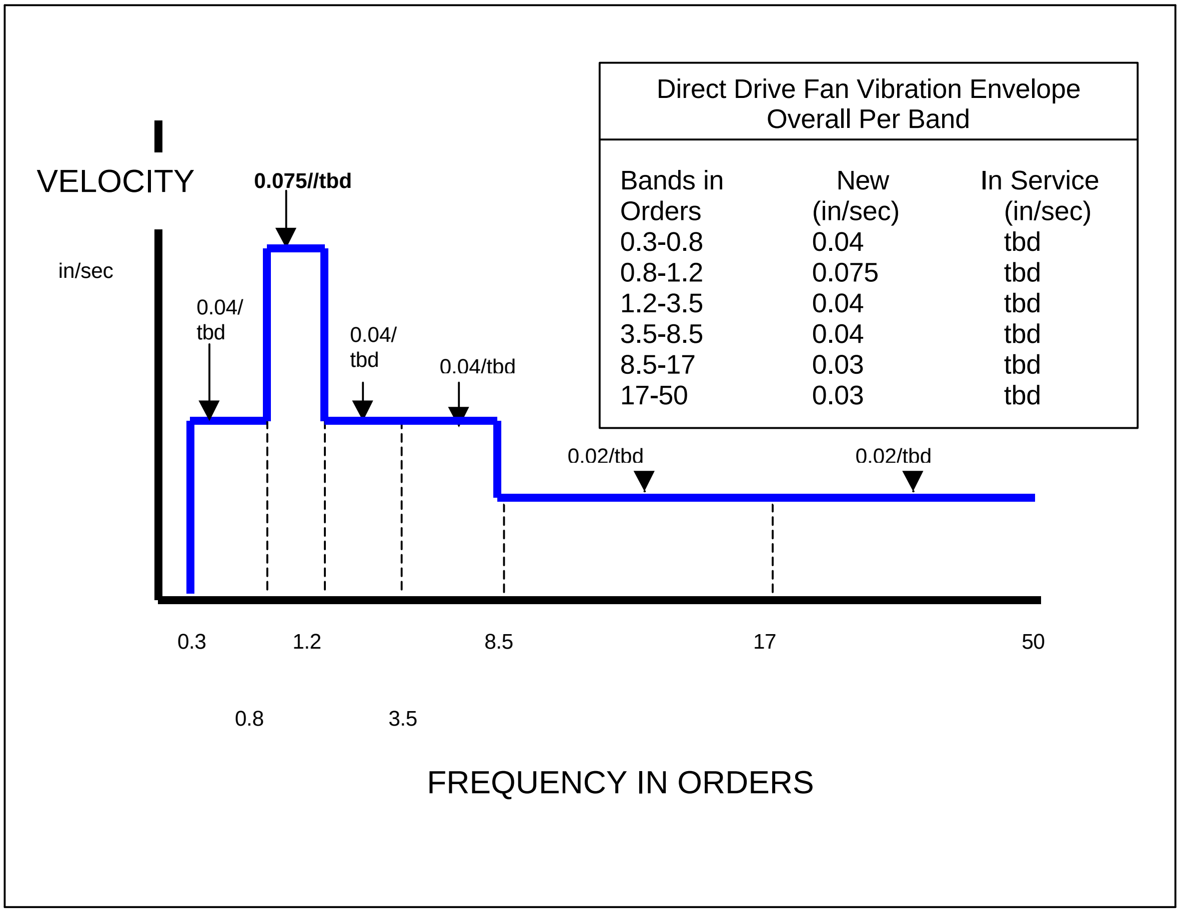


Figure 3-10. Direct Drive Fan Vibration Envelope Overall Per Band

C. Vibration Standards For Pumps.

Pumps are defined in two (2) categories:

- Positive displacement—including, but not limited to, piston, gear, and vane
- Centrifugal

Vibration readings should be taken under the following operating conditions:

- Non-cavitating, non-separating condition.
- No piping strain.
- Shaft coupling aligned.
- Suction pipe to pump conforms to the Hydraulic Institute standard for required straight run.

Certification shall be performed while the pumps are operating within design specifications.

The vibration limits for positive displacement and centrifugal pumps are shown in Figure 3-11. For the purposes of line amplitude evaluations, a "pumping frequency" (PF) band will be established. The PF band will be centered on the pumping frequency (the number of pumping elements X pump RPM). The band will extend +2 lines of resolution on either side of the line of resolution containing the pumping frequency (i.e., Bandwidth = 5 lines of Resolution).

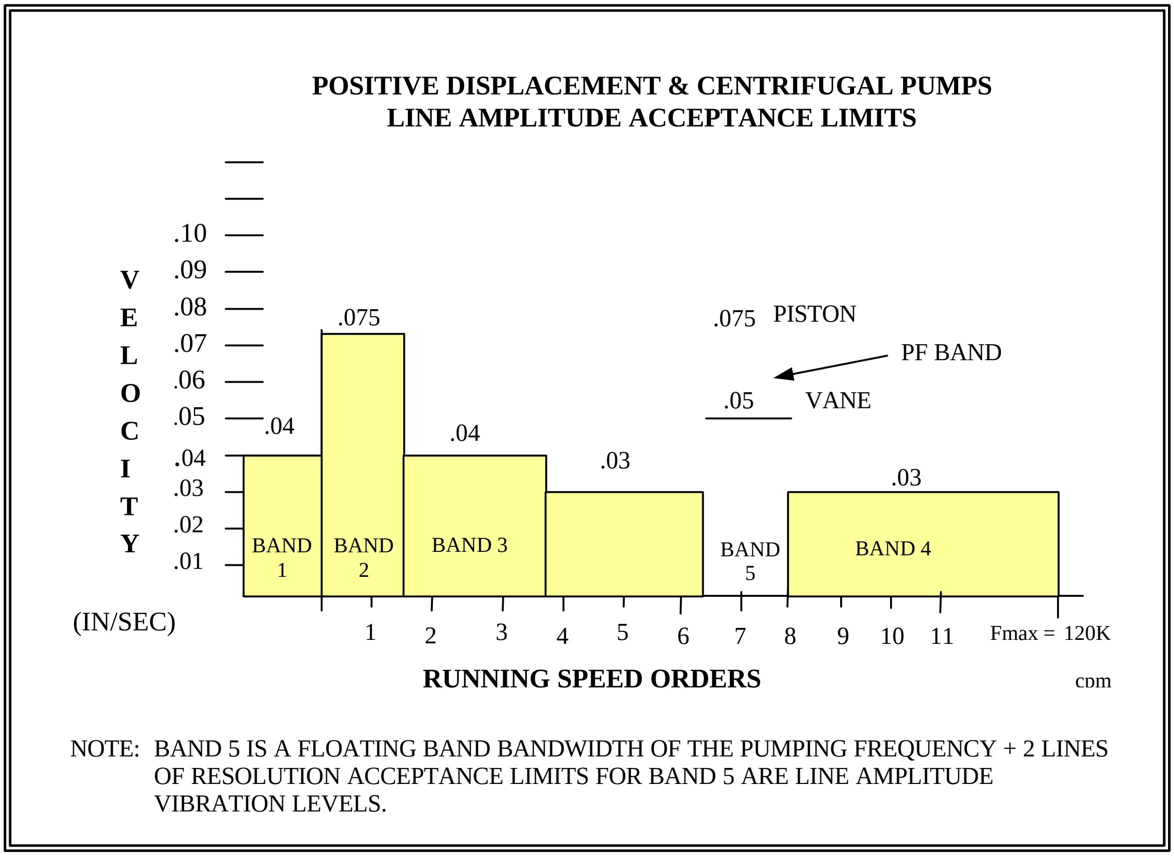


Figure 3-11. Positive Displacement and Centrifugal Pump Vibration Envelope Overall Per Band

Excluding the lines of resolution contained in the PF band, the velocity amplitude (in./sec-peak) of any line of resolution, measured at bearing locations in any direction of a positive displacement or centrifugal pump shall not exceed the line amplitude band limit values specified in Figure 3-11.

D. Vibration Standards For Gearboxes

Gearboxes shall not exceed the vibration limits specified in Figure 3-12.

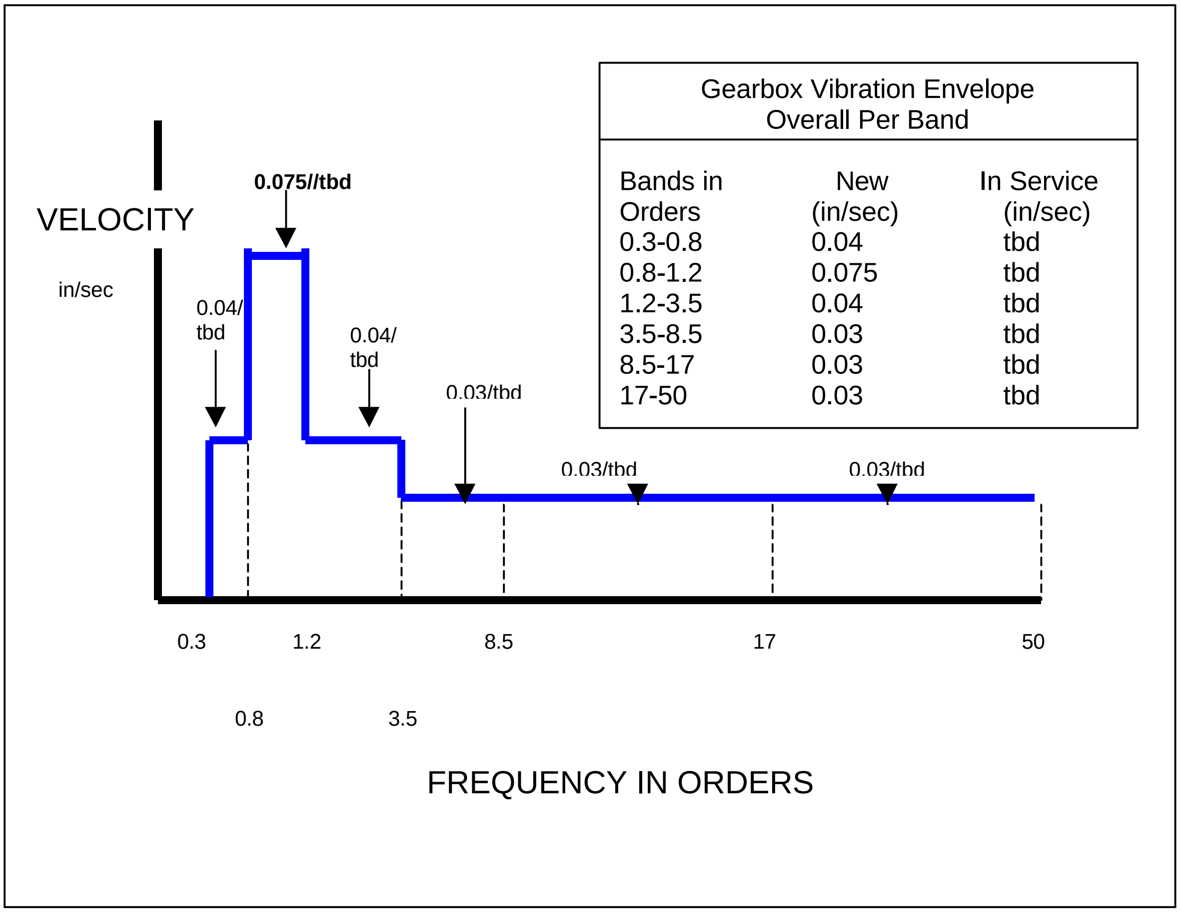


Figure 3-12. Gearbox Vibration Envelope Overall Per Band

3.3.2 Balance

This section establishes acceptable quality for the balance of new and rebuilt rotating machinery. Refer to section 3.3.1 of this guide for vibration limits. If a limit is not provided, the vibration criteria listed in Table 3-1 will be used for acceptability of the machine in question. This is a narrowband limit. An overall reading is not acceptable.

Frequency Range (CPM)	Vibration Limit (inch/sec)
0.3xRPM to 0.8xRPM	0.04
0.8xRPM to 1.2xRPM	0.075
1.2xRPM to 3.5xRPM	0.04
3.5xRPM to 120,000CPM	0.03

Table 3-1. Default Balance Criteria

3.3.2.1 Standard Key

For rotating machines and machine components with a keyed shaft, balancing will be achieved by using a standard one-half key in the key seat in accordance with ISO 8821-1989. If a “full key,” corresponding to the half key used for balancing, is not provided with the rotating machine, a tag, as shown in Figure 3-13, will be attached to the machine to indicate the dimension of the key used to perform the balance test.

Figure 3-13. Balance Test Key Dimension.

3.3.2.2 Balance Weights

Permanently attached balancing weighs must be secured by welding, bolting, or pop-riveting, or they must be of a “clip-on” design. If bolted, a hardened bolt must be used in conjunction with a mechanical locking device (e.g., lock` washer or lock nut). Clip-on balancing weights can be used only on centrifugal-type fans and must be located and attached on the ID pitch of the blades such that the rotational motion of the fan creates a positive seating of the clip-on weight against the fan blade.

Balancing weights and the method of their attachment must be stable at the equipment operating temperature and manufactured of a material that is compatible with the parent material of the fan to which the balancing weight is attached.

NOTE: THE USE OF STICK ON LEAD WEIGHTS IS NOT ACCEPTABLE.

Any parent metal removed to achieve a dynamic or static balance shall be drilled out in a manner that will maintain the structural integrity of the rotor or sheave.

3.3.2.3 Measurement Requirements For Machine Certification

Taking and documenting balance measurements are the responsibility of the contractor unless specified otherwise by NASA. The measurements must be performed by a technically qualified person who is trained and experienced in machinery balancing. The technical qualifications of the person doing the balance certification shall be submitted to the Construction Manager as a part of the machine balance certification data.

Balance quality for machine certification shall be measured prior to “run-off” at the vendor’s facility. NASA will have the option to verify the balance quality of the equipment during machine “run-off’ at the vendor’s test site prior to shipment or at the NASA Center prior to final acceptance authorization.

Where it is impractical to set up and test a complete machine at the vendor’s facility, arrangements shall be made to perform the test at the NASA Center. Under this circumstance, the shipment of the equipment does not relieve the Contractor of the responsibility for meeting the specified balance quality.

3.3.3 Alignment

The purpose of this section is to ensure that provisions for laser alignment are designed into all new and rebuilt machines. The laser alignment system used for coupled shaft alignment shall use either a combined laser emitter and laser target detector unit or separate units for its laser emitter and laser target detector.

3.3.3.1 Shaft Alignment Tolerances

All shaft-to-shaft centerline alignments shall be within the tolerances specified in Table 3-2 unless more precise tolerances are specified by the machine manufacturer or by the purchasing engineer for special applications. The tolerances specified in Table 3-2 are the maximum allowable deviations from zero-zero specifications or alignment target specifications (i.e., an intention targeted offset and/or angularity). Acknowledging that machines often move after startup because of thermal growth, dynamic load shifts, etc., the alignment parameters shall be measured and adjusted for operating conditions.

Laser alignment will be performed at the NASA Center on all shaft-coupled machines during installation of the equipment. When verifying the alignment of coupled shafts, the contractor must document and provide the following data for each set of coupled shafts at the time of functional checkout:

- Alignment tolerances used
- Soft Foot

- Vertical angularity (pitch) at the coupling point (Refer to Figure 3-14)
- Vertical offset at the coupling point.
- Horizontal angularity (yaw) at the coupling point.
- Horizontal offset at the coupling point.

	RPM	Tolerance Specification
Soft Foot	All	<0.002 inch (0.0508 mm) at each foot

	RPM	Horizontal and Vertical Parallel Offset	Angularity/Gap Inch/10 Inch (Mm/254 Mm)
Short Couplings			
	<1000	0.005 in. (1.2700 mm)	0.015 in. (0.3810 mm)
	1200	0.004 in. (1.0160 mm)	0.010 in. (0.2540 mm)
	1800	0.003 in. (0.7620 mm)	0.005 in. (0.1270 mm)
	3600	0.002 in. (0.5080 mm)	0.003 in. (0.0762 mm)
	7200	0.001 in. (0.2540 mm)	0.0025 in. (0.0635 mm)

		Horizontal and Vertical Parallel Offset Per Inch (25.4 Mm) of Spacer Length	
Couplings			
with	<1000	0.0020 in. (0.0508 mm)	
Spacers	1200	0.0015 in. (0.0381 mm)	
	1800	0.0010 in. (0.0254 mm)	
	3600	0.0005 in. (0.0127 mm)	
	7200	0.0003 in. (0.0076 mm)	

Table 3-2. Tolerances for Coupled Shaft Alignments

Piping must be fitted, supported, and sufficiently flexible such that soft foot due to movement caused by tightening pipe flanges does not exceed 0.002 in. (0.051 mm). Piping must not restrict the minimum 180-degree rotation requirement of the laser alignment system.

Shims shall meet the following specifications:

- Shims shall be commercially die-cut.
- Shims shall be made of corrosion- and crush-resistant stainless steel, which is dimensionally stable when subjected to high compression over long periods of time.
- Shims shall be consistent over the whole shim area, without seams or folds from bending.

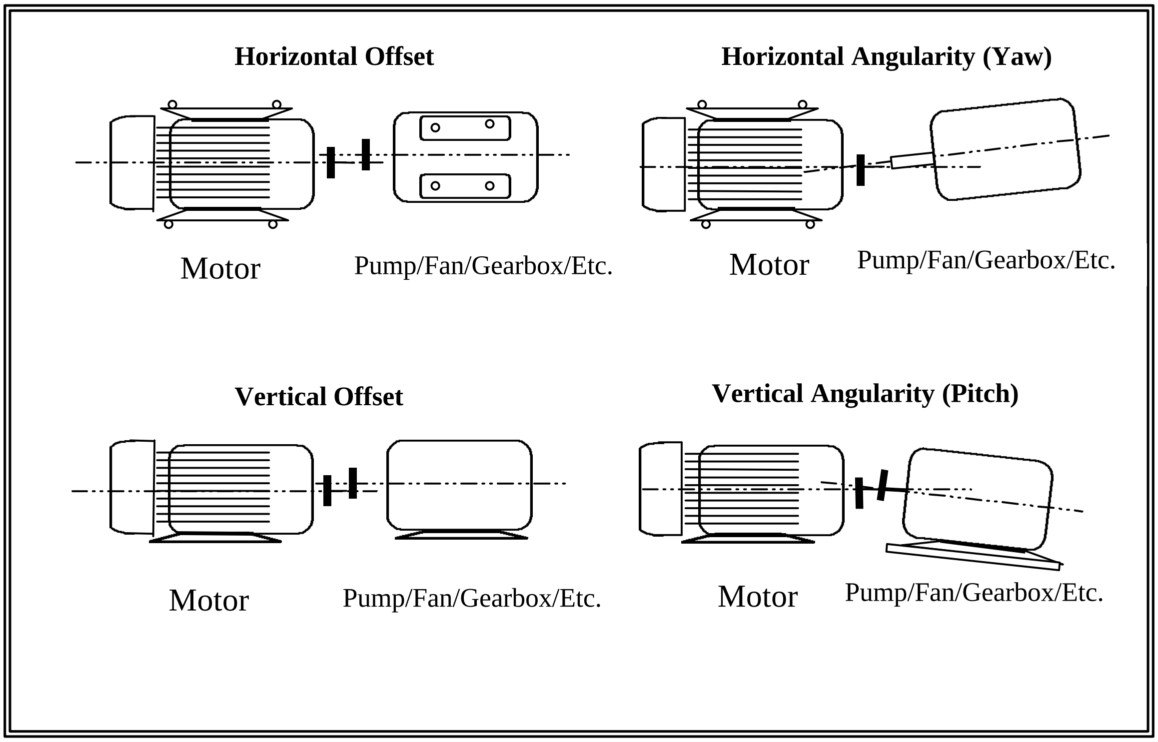


Figure 3-14. Offset and Angular Misalignment.

- Shims shall be clean, free from burrs, bumps, nicks, and dents of any kind.
- Size numbers or trademarks shall be etched (not printed or stamped) into the shim.
- The smallest commercial shim that will fit around the hold down bolts without binding shall be used.
- The overall shim pack shall not exceed a total of five (5) shims.
- Shims must rest on bare metal, not on paint or other coatings.

All machines shall be installed with a minimum of 0.125-inch (3.0-mm) dimensionally stable shims under each surface mounting point for vertical mobility.

Original Equipment Manufacturers (OEMs) must use only the couplings specified by NASA unless otherwise agreed to by NASA. During the alignment process, coupling play or backlash must be eliminated to accomplish a precision shaft alignment.

Axial shaft play or end play must be no greater than 0.125 inch (3.175 mm). The accommodation of end movement must be done without inducing abnormal loads in the connecting equipment.

3.3.3.2 Alignment Of Belt-Driven Machines

Motors will be provided with adjustable motor bases unless otherwise specified. Motors of over 5,600 watts of power will be provided with adjustable, pivoted motor bases. The base will have enough adjustment to allow for belt replacement without stretching the new belts. The adjustment method will be by the use of two adjusting bolts.

After sheaves are installed on the motor and driven shafts, the sheaves will be checked to ensure that they are true on the shaft. Runout on the sheaves shall not exceed 0.002 in. (0.0580 mm).

Unless otherwise specified, drive and driven sheaves will be aligned by the four-point method. If the sheave web thickness is not the same on the drive and driven sheave, shims of the appropriate thickness will be used on the narrower sheave for the alignment. The thickness of the shims will be recorded and supplied with the machine information to the NASA Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.4 Lubrication and Hydraulic Fluids

3.3.4.1 Hydraulic Oils

Type of System	System Sensitivity	Maximum Particle Level (particles per 100 milliliters)		
		5 microns	15 microns	ISO
Silt-sensitive control system with very high reliability	Super critical	4000	250	13/9
High-performance servo and high-pressure long-life systems	Critical	16,000	1000	15/11
High-quality reliable systems	Very important	32,000	4000	16/13
General machinery and mobile systems	Important	130,000	8000	18/14
Low-pressure heavy industrial systems	Average	250,000	16,000	19/15
Low-pressure systems with large clearances	Main protection	1,000,000	64,000	21/17

Table 3-3 Sperry Vickers Table Of Suggested Acceptable Contamination Levels For Various Hydraulic Systems

All bulk and equipment-installed hydraulic fluids supplied shall meet the cleanliness guidelines in Table 3-3. NASA will specify the system sensitivity.

The particle counting technique used must be quantitative. Patch test results are not acceptable.

3.3.4.2 Lubrication Oils

The contractor must provide to NASA the following information on all lubricants supplied in bulk or contained within equipment supplied under this contract:

Liquid Lubricants

- Viscosity grade in ISO units
- AGMA and/or SAE classification as applicable
- Complete identification of all additive package compounds

Grease Lubricants

- Type of base stock
- NLGI Number
- Type and percent of thickener
- Dropping point
- Base oil viscosity range in SUS or centipoise

The contractor must identify all lubricants and perform the lubricant tests listed in Table 3-4 on all lubricants supplied by the contractor. The results of the tests shall be submitted to the NASA Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

Lubricant Tests	Testing For	Limits
Total Acid Number	pH balance	<.05 gm KOH/ml
Visual	Cloudiness	Non-cloudy
IR Spectral Analysis	Metals	None
Particle Count	Particles >10um	< 100
Water Content	Water	< 25ppm @ 20^{o}C
Viscosity	Lubricating Quality	Per Spec.

Table 3-4. New Lubricating Oil Limits

3.3.5 Airborne Ultrasonics

Airborne ultrasonic devices operate in the frequency range of 20kHz to 100kHz and transpose the high frequency signal into the audible range in order to allow the operator to hear noise associated with leaks, electrical arcing, and other high frequency events. Airborne ultrasonic test kits generally consist of a receiver “gun” with variable frequency select, a set of ear-isolation headphones, various contact probes, and various tone generators for placement into heat exchangers, boilers, etc. The following applications apply to all airborne ultrasonic devices.

3.3.5.1 Heat Exchangers

The contractor may test heat exchangers by either of the following methods:

- Warble Tone Generator—An ultrasonic source is placed inside the area to be tested (one tone generator is required for each 4,000 cubic feet of volume), the instrument is set on scanning mode, log position, and fixed band. The tone generator can be attached to an adapter at the end of a pipe to flood the pipe, heat exchanger shell, or tube bundle. A scan is then performed on the pipe or tubes.
- Differential Pressure Method—Equitable gas is inserted between the inspection area and the scanning location. A general scan of the area is then performed. When checking the tubes, the tubes are blocked, one at a time, and the differences in readings noted. Any tubes suspected of leakage should then be marked.

A general scan of the equipment is performed with the sensitivity set to maximum in the fixed band mode. As the search area is reduced, the rubber probe is attached to narrow the pickup area and reduce the equipment’s sensitivity.

Ultrasonic reading results (data) and signatures of the contractor and of the NASA Construction Manager must be obtained before acceptance of the heat exchanger will be authorized. Defective heat exchangers shall be rejected. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.5.2 Boilers

The contractor shall use ultrasonics to verify the integrity of the boiler casing and its associated piping. Using a contact probe, the contractor operator can listen to the internal tubing of the boiler housing.

Ultrasonic reading results (data) and signatures of the contractor and of the NASA Construction Manager must be obtained before acceptance of the boiler will be authorized. Defective boilers shall be rejected. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.5.3 Steam Traps

Steam traps must be monitored on the downstream side of the trap. The contact probe should be attached to the sensor and the sensor set at or near the 25kHz band. Most steam traps produce intermittent sounds from opening and closing. Most traps found with continuous flows or no flows whatsoever should be checked for proper operation. The five types of steam traps are as follows:

- Intermittent Traps—The operator will hear an open and closing sound. The trap normally fails in the open position, producing a continuous, rushing sound.
- Inverted Bucket—A normal trap sounds as if it is floating; a failed trap sinks, producing a continuous flow noise.
- Thermostatic—Ultrasonic testing results of this type of trap vary. The noise produced by these traps can be continuous or intermittent and will produce different sounds accordingly.
- Float and Thermostatic (Continuous Load)—Flow and noise associated with these traps are usually modulated. Failed traps are normally cold and silent.
- Continuous Flow—This type of trap, when operating normally, produces the sound of condensate flow only. If it has failed in the open position, a continuous flow sound should be heard.

The use of ultrasound to detect steam leaks both in new and existing installations can have substantial economical benefit for the Center. Table 3-5 provides an estimate of the monthly steam loss resulting from various size leaks. When all applicable costs associated with each pound of steam are calculated, the result is a budgetary burden the Center can ill-afford.

Leak Diameter (inches)	Steam Loss per Month (lbm)
1/64	3,300
1/32	6,650
1/16	13,300
1/8	52,200
1/4	209,000
1/2	833,000

Table 3-5. Estimated Steam Loss

Ultrasonic reading results (data) and signatures of the contractor and of the NASA Construction Manager must be obtained before acceptance of the steam traps will be authorized. Defective steam traps shall be rejected. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.5.4 Piping Systems

Traditional and Total Building commissioning tests for water, plumbing and air distribution systems first require a pressure test of all piping, seals and fittings. During this test, an ultrasonic scan should be performed on all accessible piping and distribution systems to help discover any leaks. Additionally:

- For hot water systems, after the pressure and hydro tests are completed and after piping insulation has been installed, the system should be charged with hot water and an infrared scan performed to verify insulation integrity.

- For steam systems ultrasonic scans should be performed on steam traps.

- For process/vacuum systems ultrasonic scans should be performed on all connections and fittings.

Ultrasonic reading results (data) and signatures of the contractor and of the NASA Construction Manager must be obtained before acceptance of the piping system will be authorized. Defective piping, joints, seals and related components shall be rejected. This information should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.3.5.5 Bearings

Airborne ultrasonics can be used to detect bearing problems, but it is not the preferred method. Vibration analysis is recommended.

3.4 Electrical Systems

Table 3-6 indicates the most appropriate PT&I tests for the acceptance of electrical systems.

3.4.1 Infrared Imaging

IRT can be used to identify safety hazards and other latent manufacturing and installation defects in facilities' electrical systems, such as transformers, motor control centers, switchgear, substations, electrical panels, and power lines. It should be noted that for meaningful infrared data to be recorded the loading of the circuit should be at least 50%.

For new or rebuilt electrical equipment, an infrared inspection by the appropriate maintenance organization (i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc.) should also be accomplished within 90 days of system/facility turnover. Although it is recognized that facility acceptance would have already taken place, this will allow for any initial anomalies for which the contractor is still responsible under the terms of the construction contract warranty to develop and become apparent to the inspector.

To be effective in facilities applications, the IRT instruments must be portable, sensitive to within 0.2^{o} C over a range of -10^{o} C to $+300^{o}$ C, and accurate to within 2%. Additionally, the instrument must be capable of storing an image of the thermogram for later use and analysis.

Electrical Equipment	Power Factor Tests	Excitation Tests	Insulation Resistance	Infrared	Ultrasonic	Battery Impedance	Breaker timing	Insulating Oil Condition	Partial Discharge	Contact Resistance	High Voltage Testing	Motor Circuit Analysis	Turns Ratio Tests	Dissolved Gas Analysis
Transformers	●	●	●	●	●			●					●	●
Circuit Breakers	●		●	●	●		●	●		●	●	●		
Motors	●		●	●					●		●	●		
Batteries				●		●								
Motor Control Centers			●	●	●							●		
Switchgear	●		●	●	●					●	●			
Power Panels			●	●	●									
Power Cables	●		●						●		●			

Table 3-6. Electrical System PT&I.

Table 3-7 shows typical temperature differences relative to a given baseline (delta T) criteria used in both industry and the military for in-service electrical equipment. For new equipment, any temperature rise over the reference temperature should be investigated and repaired.

It should be noted that the indicated values are for equipment at 50% loading or greater. As the loading becomes less, the delta T values become less.

Criticality	Temperature above reference, Mil Spec	Temperature above reference, Industry	Condition
Nominal	10 to 25C^{o}	0 to 10C^{o}	Nominal possibility of permanent damage, repair next maintenance period.
Intermediate	25 to 40C^{o}	10 to 20C^{o}	Possibility of permanent damage, repair soon.
Serious	40 to 70C^{o}	20 to 40C^{o}	Probability of permanent damage to item and surrounding area, repair immediately.
Critical	Over 70C^{o}	over 40C^{o}	Failure imminent

Table 3-7. Infrared Temperature Criteria

Figure 3-15 is an infrared image of a 120-volt power panel. Note the relative temperature differentials indicative of a poor connection. Figure 3-16 is an infrared image of a defective Motor/coupling.

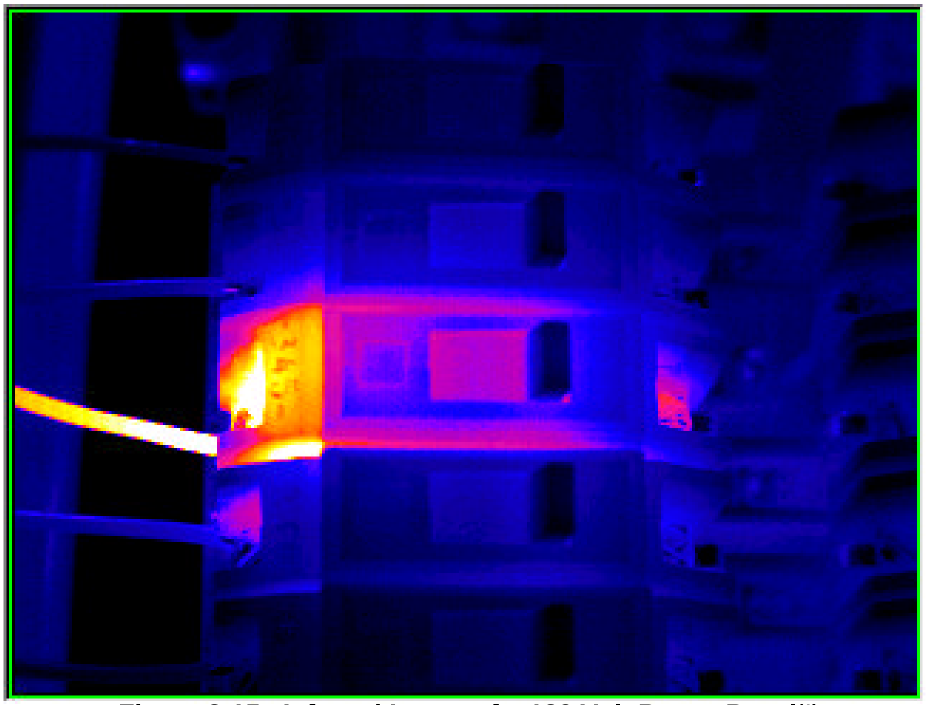


Figure 3-15. Infrared Image of a 120 Volt Power Panel[15]

3.4.2 Insulation Power Factor Testing

Power Factor, sometimes referred to as "dissipation factor", is the measure of the power loss through the insulation system to ground. It is a dimensionless ratio that is expressed as a percent of the resistive current flowing through an insulation relative to the total current flowing. To measure this value, a known voltage is applied to the insulation, and the resulting current and current/voltage phase relationship is measured. Figure 3-17 shows the phase relationships of the resulting currents. I_T is the resistive current, I_c is the capacitive current, I_T is the resultant, or total current, and V is the applied voltage.

Usually, I_R is very small compared to I_T because most insulation is capacitive in nature. As a comparison, the reader should consider the similarities between a capacitor and a piece of electrical insulation. A capacitor is two current carrying plates separated by a dielectric material. An electrical coil, such as that found in a transformer or motor, is a current carrying conductor with an insulation material protecting the conductor from shorting to ground. The conductor of the coil and ground is similar to the two conducting plates in the capacitor. The insulation of the coil is like the dielectric material of the capacitor. The dielectric material prevents the charge on

[15] Figure provided by Michoud Assembly Facility (Lockheed Martin)

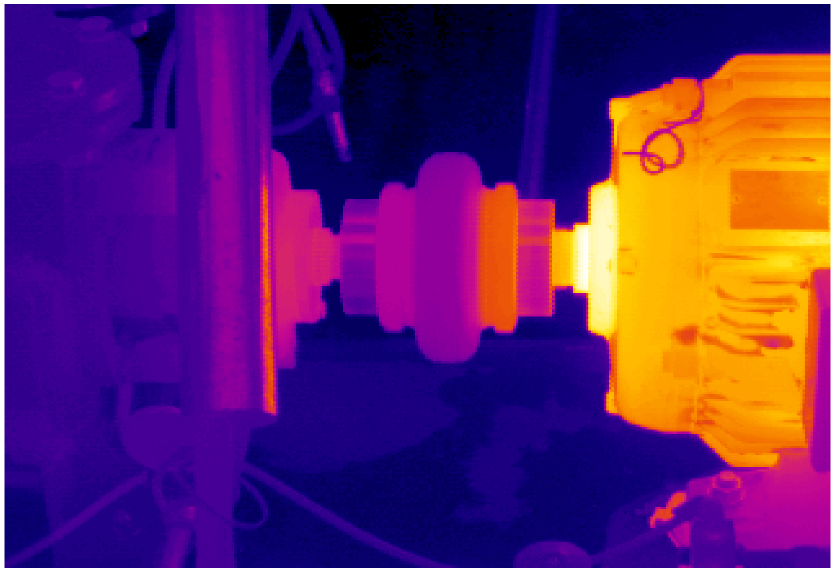


Figure 3-16. Infrared Image of Motor/coupling[16]

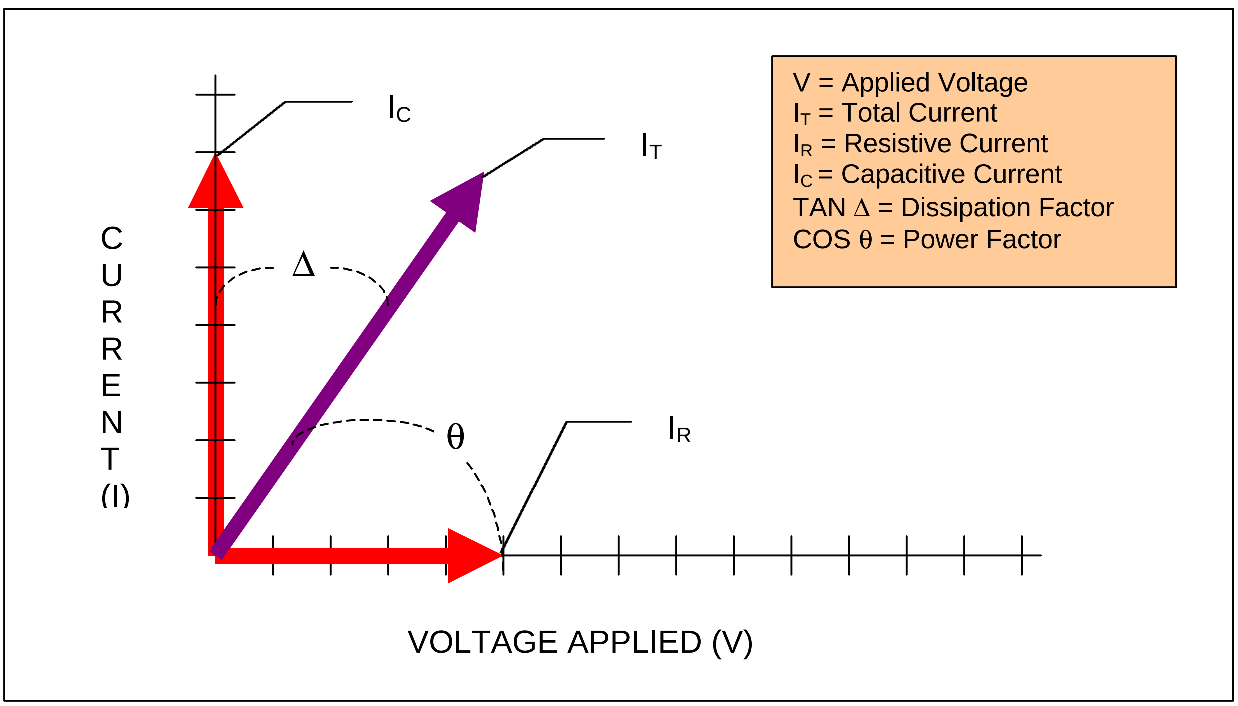


Figure 3-17. Phase Relationships

[16] Figure provided by Kennedy Space Center (SGS)

each plate from "bleeding through" until such time when the voltage level of the two plates exceeds the voltage capacity of the dielectric. The coil insulation prevents the current from flowing to ground, until the voltage level exceeds the voltage capacity of the insulation.

Referring back to Figure 3-17, it can be seen that I_R is in phase with the applied voltage V, and I_C is leading the voltage by a phase angle of 90 degrees. The total current is the resultant combination of both I_R and I_C. The tangent of the angle between the applied voltage and resultant current is called the "dissipation factor", and the cosine of the angle between the resultant current and the capacitive current is called the "power factor".

As the impedance of the insulation changes due to physical damage, insulation shorts, moisture, contamination, or aging the ratio between I_C and I_R will become less. The resulting phase angle between the applied voltage and resultant current then becomes less, and the power factor will rise. Consequently, the power factor test is used for making routine comparisons of the condition of an insulation system and for acceptance testing to verify that the equipment had been manufactured and installed properly. The test is non-destructive, and regular follow-on maintenance testing will not deteriorate or damage the insulation.

The power factor can be measured in three ways:

- Grounded Specimen Test (GST) – A voltage is applied to the circuit under test and all leakage current flowing through the insulation to ground is detected. Grounding leads are provided for the return path. This test provides a good overall test of the circuit.
- Ungrounded Specimen Test (UST) – A voltage is applied to the circuit under test and a direct measurement on only a portion of the circuit can be accomplished. Any currents flowing to ground are not measured. This test is good for isolating a reading for troubleshooting.
- GST with Guard – A voltage is applied to the circuit under test and all leakage current flowing through the insulation to ground is detected. However, an additional lead is attached to the circuit and any leakage current up to that part of the circuit will be bypassed by the measuring circuit. This test is good for troubleshooting.

Table 3-8 contains typical insulation power factor values of electrical equipment. All power factor test results must be corrected to 20^{o}C for comparison purposes. Test set manufacturers' instruction manuals should be consulted for the appropriate correction tables.

Limitations – Power factor readings should not be taken under the following conditions:

- High humidity – humid conditions over 75% can result in excessive surface leakage currents on exposed surfaces.
- Freezing ambient temperatures – power factor tests are very sensitive to moisture; however, frozen water becomes non-conducting and defects or degradation can remain hidden. This temperature limitation does not apply to insulation oils.
- Dirty or contaminated surfaces – poor surface conditions result in excessive leakage currents that will be added to the losses and may give a false impression of the test.

Equipment Type	% PF at 20°C
Oil Filled Transformer: New, high-voltage 15 year old, high-voltage Medium-voltage distribution	0.25 to 1.0 0.75 to 1.5 1.5 to 5.0
Dry type transformer (>600V)	1.0 to 7.0
Oil Circuit Breakers (5KV and up)	0.5 to 2.0
Air Circuit Breakers (5KV and up)	0.5 to 2.0
Oil-Paper Cables: solid (up to 27KV) new condition High-voltage oil-filled or pressurized (to 69KV)	0.5 to 1.5 0.2 to 0.5
Rotating machines stator windings, 2KV to 13.8KV	2.0 to 8.0
Capacitors (resistor out of circuit)	0.2 to 0.5
Bushings: Solid or dry Compound filled up to 15KV Compound filled 15KV to 46KV Oil-filled below 110KV Oil-filled 110KV and up	3.0 to 10.0 5.0 to 10.0 2.0 to 5.0 1.5 to 4.0 0.3 to 3.0

Table 3-8. Power Factor Values

Authorization for electrical system acceptance based on insulation power factor testing requires a signature by the NASA Construction Manager. This information along with all test data should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.4.2.1 Circuit Breakers (Above 600 Volts)

Circuit breakers should first be power factored in the open position using the Grounded Specimen Test. The porcelain surface of bushings should be clean and dry prior to beginning the test. The load and line side of each phase should read within 10% of each other and the factory test results. See Table 3-8 for the maximum power factor values along with the appropriate test voltages. Any larger difference should be investigated and repaired prior to acceptance. The breaker should then be closed, the load and line side bushings tied together, and then power factored. As before, each phase should be within 10% of the other two phases, and anything greater should be investigated and repaired. The manufacturer's instructions and factory test data should be consulted for comparisons.

Circuit Breakers rated 15KV and above should also have their bushings power factored. Breaker bushings rated 69KV and above should have the factory power factor and capacitance values stamped on the bushing base.

3.4.2.2 Motors (Tip-Up)

A motor should be tested using a GST test. Ideally, each phase should be tested individually, so this test must be accomplished prior to terminating the motor at the terminal box.

3.4.2.3 Switchgear And Motor Control Centers

For switchgear rated 5KV and above the buss should be power factored to the values shown in Table 3-9.

Power Factor Values		
Voltage Rating (Volts)	Test Voltage (Volts)	Maximum Reading
5000	5000	2%
7000	5000	2%
15,000	10,000	2%
35,000	10,000	2%

Table 3-9. Switchgear Power Factor Values

3.4.2.4 Transformers

Insulation Power factor is applicable to transformers with at least one winding rated 5KV or higher. (Low voltage transformers have not been shown to benefit from insulation power factor testing.) Both the high voltage and low voltage windings of a transformer should be power factored. The results of this test should be compared to the factory test to confirm that no damage occurred to the unit during shipping and installation. Additionally, these results should be used for the unit's initial baseline for condition monitoring purposes.

Insulation power factor is typically performed at rated voltage up to a maximum of 10KV. Manufacturer's instruction manuals and IEEE Standard 62-95, *IEEE Guide for Diagnostic Field Testing of Electrical Apparatus – Part 1: Oil Filled Power Transformers, Regulators, and Reactors*, or IEEE Standard C57.12.91-1995, *IEEE Standard Test Code for Dry Type Distribution and Power Transformers*. Typical connection diagrams are shown in Figures 3-18 for transformers and 3-19 for bushings.

For new oil and gas filled units the insulation power factor should not exceed 1.0%. Any values obtained over this value should be investigated and the unit not energized until a reason for the excessive reading is found. For dry type units, power factor standards have not been established due to the hydroscopic characteristics of the windings. Consequently, the most useful method of evaluation is comparison with the factory test results.

The condition of the core and turn insulation can be monitored using an excitation current test. This test uses a simple measurement of a single-phase current on one side, usually the high voltage side of a transformer with the other side left floating (ungrounded). The test should be performed at the highest possible voltage level without exceeding the rating of the windings. For effective comparisons, the same voltage should be used for subsequent tests. Units with load tap changers should have readings taken at the neutral tap position and one position both higher and lower.

The best approach to the analysis is to compare the results with the factory tests or with other identical units. For three phase units the normal pattern is two similar high readings on the outer phases and one lower reading on the center phase. The relationship between outer and center phases should remain the same as a percentage at all tap changer positions.

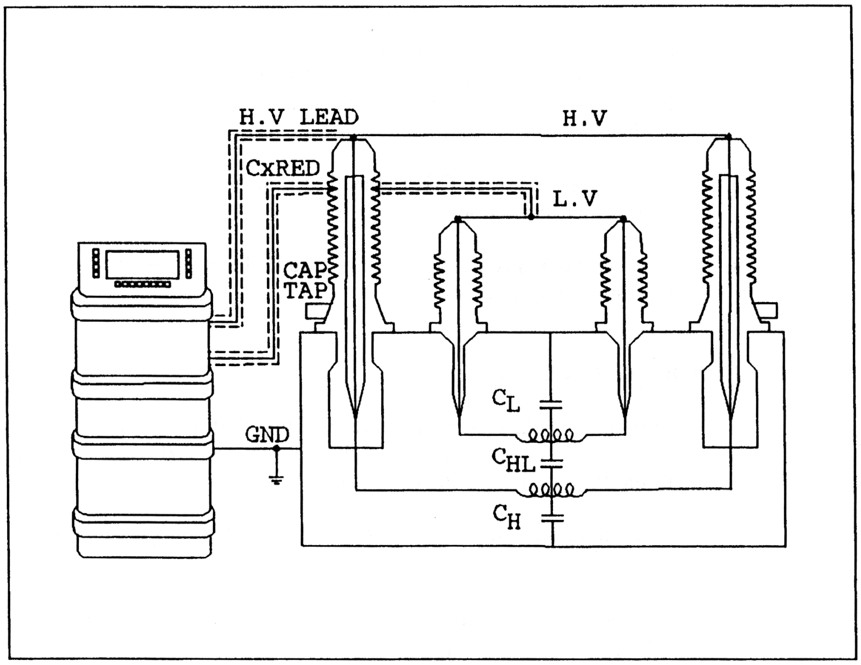


Figure 3-18. Typical Power Factor Connection to a Transformer

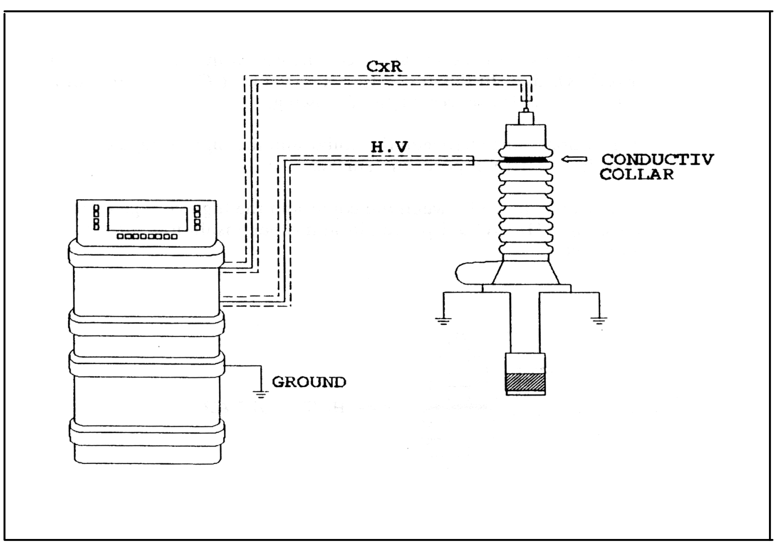


Figure 3-19. Typical Power Factor Connection to a Bushing

3.4.3 Insulation Resistance Testing

An insulation resistance test is a non-destructive direct current (DC) test used to determine the insulation resistance to ground. A DC voltage is applied to the equipment under test resulting in a small (hopefully) current flow. The total current through and along the insulation is made up of three components:

- The Capacitance Charging Current - This current is actually “charging” the insulation up to the applied voltage, just like a capacitor, hence the term “Capacitance Charging”. This current starts high and very rapidly falls off to zero after the insulation has been fully charged.
- The Dielectric Absorption Current - This current results from absorption within imperfections in the insulation. These imperfections cause voltage polarization, the most predominant being interfacial types found at the interfaces between different materials, such as the insulation paper and the copper coil found in the windings of transformers. This current starts high and decreases rapidly with time.
- The Leakage Current - The leakage current is the most important component of the insulation resistance test when attempting to evaluate the condition of the insulation under test. The path of this current can be either through the insulation itself to ground, or over leakage surfaces. While the other two currents are essentially temporary charging currents, this current actually represents a current loss. Theoretically, the leakage current should be constant with time for any single voltage value. This is an indication that the insulation under test can withstand the voltage being applied. However a steady increase in the leakage current with time at the same applied voltage indicates an abnormality in the insulation, and the test should be stopped and the equipment examined.

The insulation resistance generally is accepted as a reliable indication of the presence of contamination or degradation. However, test results can vary greatly due to environmental conditions - specifically, temperature and testing methods. Consequently, tests should be carried out under the same conditions and by the same personnel to ensure consistent values. If readings are taken at different temperatures, they should be corrected to 20 degrees C to ensure the comparisons are accurate. Table 3-10 contains correction factors for temperatures.

Temperature	Correction	Temperature	Correction
0C (32F)	0.25	20C (68F)	1.00
5C (41F)	0.36	30C (86F)	1.98
10C (50F)	0.50	40C (104F)	3.95
15C (59F)	0.72	50C (122F)	7.85

Table 3-10. Insulation Resistance Temperature Correction Factors

Taking the insulation resistance test a step further, the resistance readings can be recorded at 15-, 30-, 45-, and 60-seconds, and at 1-minute intervals up to 10 minutes. These readings can then be plotted on log-log graph paper. The resulting curves should have a smooth rise over the test time.

For condition monitoring purposes, the best application for the insulation resistance test is the Polarization Index (PI) or the Dielectric Absorption Ratio (DAR). The PI is the ratio of the ten-minute resistance to the one-minute resistance, and the DAR is the 30-sec reading divided by the one minute reading. The resulting values are dimensionless and do not need any temperature correction. They are purely numeric and offset the fact that previous test information might not be available. Since leakage current increases much faster in insulation with moisture or other contaminates present, the PI and DAR ratios will be lowered for insulation that is in poorer condition. In a condition monitoring program using insulation resistance, the PI is the value that is trended.

Authorization for electrical system acceptance based on insulation resistance testing requires a signature by the NASA Construction Manager. This information along with the test data should be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.4.3.1 Motors

On motors 200HP and above, the contractor is to perform an Insulation Resistance test and Polarization Index test on each phase of the motor prior to terminating the motor to the feeder cable. On motors below 200HP, an Insulation Resistance and DAR test should be performed. On motors where the phases can not be separated, all three phases are to be tested together. Insulation tests on motors up to 2,400 volts shall be conducted using 2,500 volts DC. Insulation tests on motors rated above 2,400 volts shall be conducted using 5,000 volts DC.

Data recorded shall be megohm readings relative to time. Readings shall be taken at 15-, 30-, 45- seconds and in 1-minute increments thereafter up to 10 minutes. Megohm readings shall not be less than 25 megohms for each phase, and each phase reading shall be within 10% of the other two.

The polarization index of each phase shall be calculated by dividing the 10-minute reading by the 1-minute reading. The polarization index shall be greater than 1.25. Any values lower than 1.25 shall be rejected and the motor not accepted by NASA.

The DAR of each phase is to be calculated by dividing the 30-second reading by the 1-minute reading. The DAR shall be greater than 1.25. Any values lower than 1.25 shall be rejected and the motor not accepted by NASA.

3.4.3.2 Switchgear And Motor Control Centers

Bus insulation for both switchgear and motor control centers should be measured with the limits displayed in Table 3-11.

Readings below the minimum values are indicative of improperly installed or wet insulation or loose bus connections and should be resolved prior to continuing testing and commissioning.

Insulation Resistance Values		
Voltage Rating (Volts)	**Minimum Test Voltage (Volts)**	**Minimum Resistance (megohms)**
250	500	25
600	1000	100
2400	2500	250
5000	2500	1000
7000	5000	2000
15,000	5000	5000

Table 3-11. Bus Insulation Resistance Values

3.4.3.3 Circuit Breakers

Insulation Resistance (Megger) values, measured for each phase, should be over 25 megohms for molded case breakers and over 100 megohms for all others.

3.4.3.4 Transformers

Insulation resistance measurements are to be performed by the contractor to verify that the state of dryness of the winding insulation and the core is acceptable. Insulation resistance tests can also reveal information about concealed damage to bushings that can occur during shipment and/or storage. Measurements normally are performed on transformers at rated voltage up to a maximum of 5,000 volts. It is very important for the temperature of the insulation system to be known when performing the test. Insulation resistance is very sensitive to temperature and varies inversely with temperature. Insulation resistance measurements must be corrected to 20 degrees C for comparison purposes. When the test is performed, the core should be grounded and the windings under test short-circuited. Those windings that are not being tested should be grounded, and all bushings should be cleaned prior to beginning the test.

The minimum resistance values depend on the voltage and capacity of the unit under test. For acceptance tests, the minimum value should be determined using the following equation:

Where: R = Minimum resistance corrected to 20^{o}C

C = Constant (0.8 for oil transformers, 16 for dry type)

E = Voltage rating of the winding under test

kVA = Rated capacity of winding under test

The results of the test should also be compared with the factory results and should be within 5% of the factory readings after correction to 20^{o}C.

Large transformers can sometimes have long charging times due to the absorption current. When this is the case, the polarization index (PI) can be used. PI is a ratiometric test that will help identify the condition of the insulation even if the charging currents have not diminished to zero. The test lasts for 10 minutes. The one-minute and 10-minute insulation resistance readings are recorded. The PI is the 10-minute reading divided by the one-minute reading. For a new transformer, the PI should be greater than 2.

3.4.4 Insulation Oil Testing

High and medium voltage transformers, some high and medium voltage breakers, and some medium voltage switches are supplied with mineral oil as an insulation medium. Performing oil tests by the Contractor prior to turnover is needed to ensure that the proper oil is installed and that the necessary inhibitors have been added.

Authorization for electrical system acceptance based on insulation oil testing requires a signature by the NASA Construction Manager. This information should be provided along with all test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

The two groupings of testing required of the contractor for facility and equipment acceptance are Dissolved Gas Analysis and oil condition tests.

A. Dissolved Gas Analysis

Dissolved gas analysis, also called "gas-in-oil analysis", is probably the best predictive test for oil filled transformers. As transformers age, small amounts of combustible gases are formed. However, when insulation systems are subjected to stresses, such as fault currents and overheating, combustible gas generation can change dramatically. In most cases, these stresses can be detected early on; the presence and quantity of the individual gases can be measured and the results analyzed to indicate the probable cause of the gas generation.

Using ANSI Standard D-3613, the contractor shall draw a small oil sample (50cc) from the transformer with a glass syringe. To obtain a reliable reading, this must be accomplished with the unit energized. As a transformer cools after being taken off-line, dissolved gases in the oil migrate into the windings so any sample taken after cooldown will not be representative of the true “on-line” condition.

The oil is then analyzed using ASTM D-3612-90, *Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography*. While there are over 200 gasses present in insulating oils, there are only nine that are of concern. They are:

- Nitrogen (N_2)
- Oxygen (O_2)
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)

- Methane (CH_4)
- Ethane (C_2H_6)
- Ethylene (C_2H_4)
- Hydrogen (H_2)
- Acetylene (C_2H_2)

Standards for gas-in-oil are listed later in this section.

B. Insulation Oil Condition

Below is a list of the available tests, their ASTM standard number, and a brief description of what each test reveals.

- *Karl Fisher, ASTM D-1533-88.* Tests for water in insulating fluids. This test reveals the total water content in oil, both dissolved and free. High readings could indicate a leak in the equipment housing or insulation breakdown.
- *Dielectric Breakdown Strength, ASTM D-877 and D-1816*. Tests for conductive contaminants, such as metallic cuttings, fibers, or free water, present in the oil.
- *Neutralization Number, ASTM D-974*. Commonly called the "acid number", this measurement shows the amount of acid in the oil. The acidity is a result of oxidation of the oil caused by the release of water into the oil from insulation material due to aging, overheating, or operational stresses such as internal or through faults. The acidity is measured as the number of milligrams of potassium hydroxide (KOH) it takes to neutralize the acid in one gram of oil. An increase in the acidity indicates a deterioration of the oil. This process causes the formation of sludge within the windings, which in turn can result in premature failure of the unit.
- *Interfacial Tension(IFT), ASTM D-971*. Measures the tension at the interface between two immisible liquids, oil and water. It is expressed in dynes/centimeter. This test is extremely sensitive to oil decay products and contamination from solid insulating materials. Good oil will have an IFT of 40 to 50 dynes/cm and will normally “float” on top of water. As transformer and breaker insulation ages, contaminates such as Oxygen and free water are released into the oil. The properties that allow the oil to “float” on top of the oil then begin to break down and the result is a lower IFT. Along with the neutralization number, the IFT can reveal the presence of sludge in insulating oils.
- *Color, ASTM D-1524.* As insulating oils in electrical equipment age, the color of the oil tends to gradually darken. A marked color change from one year to the next indicates a problem.
- *Sediment, ASTM D-1698.* Indicates deterioration and/or contamination of the oil.
- *Power Factor, ASTM D-924*. Taken at 25 degrees C, this test can reveal the presence of moisture, resins, varnishes, or other products of oxidation or foreign contaminates, such as motor oil and fuel oil. The power factor of new oil should always be below .05%.

- *Visual Examination, ASTM D-1524.* Good oil is clear and sparkling, not cloudy and dull. Cloudiness indicates the presence of moisture or other contaminates. This is a good, "quick look" field test; however a Karl Fisher or a Dielectric Breakdown test is much more definitive.

3.4.4.1 Circuit Breakers

For oil filled breakers, the contractor should perform a dielectric and acidity test. The dielectric should be above 28KV and the acidity less than .03 gm KOH/ml.

3.4.4.2 Transformers

A. Dissolved Gas Analysis

This test can show many problems internal to an oil filled transformer before the problem becomes terminal. As events occur inside a transformer (some of which are normal) gases are liberated into the oil. Specifically, the primary causes of these gases are thermal, mechanical, and electrical stresses in the windings. Consequently, it is important that the contractor checks to make sure that the new oil has no contaminants, especially combustible gases.

As described above, the contractor will obtain an oil sample from the transformer and analyze it for combustible gases. The limits shown in Table 3-12 must be observed.

Dissolved Gas Limits For New Insulating Oil	
Nitrogen (N_2)	< 100 ppm
Oxygen (O_2)	< 10 ppm
Carbon Monoxide (CO)	< 10 ppm
Carbon Dioxide (CO_2)	< 100 ppm
Methane (CH_4)	None
Ethane (C_2H_6)	None
Ethylene (C_2H_4)	None
Hydrogen (H_2)	None
Acetylene (C_2H_2)	None

Table 3-12. Dissolved Gas Limits For New Insulating Oil

B. Oil Condition

Oil is the lifeblood of an oil filled transformer. As with Dissolved Gas analysis, oil condition tests can reveal many problems internal to a transformer, so it is important for the new oil to be "clean" and baselines established.

The oil condition tests to be performed by the contractor should be the visual test, color test, dielectric breakdown test, the power factor test, Karl Fischer test, interfacial tension test, and the acidity test. Acceptable values are listed in Table 3-13.

Oil Condition Tests and Limits for New Oil	
Color	<3.0 on the ASTM D-1524 color scale
Dielectric Breakdown	>30 kV
Power Factor	<0.15 at 25^{o}C
Karl Fischer (Water in the Oil)	<25 ppm at 20^{o}C
Interfacial Tension	>40 dynes/cm
Acidity (Neutralization Number)	<.05mg KOH per gram oil

Table 3-13. Oil Condition Tests and Limits For New Oil

3.4.5 Motor Circuit Evaluation and Analysis

3.4.5.1 Motor Circuit Evaluation (MCE)

The total impedance of a motor is the sum of its resistance, capacitance, and inductance. Any impedance imbalances in a motor will result in a voltage imbalance. Voltage imbalances result in higher operating current and temperatures, which will weaken the insulation and shorten the motor's life. An MCE test measures the resistance, inductance, and capacitance characteristics of a motor and the motor circuit. For resistance, the maximum allowable percentage imbalance is 2%. For inductance the maximum allowable percentage is 10%. The percent imbalance is calculated as follows:

$$\%\ \text{imbalance} = \frac{(R^{high} - R^{ave})}{R^{ave}} \ \text{times } 100$$

Where $R^{ave} = \frac{R1 + R2 + R3}{3}$

The formula is the same for impedance imbalance. The capacitance value is used for trending purposes and indicates wet or dirty windings.

Authorization for electrical system acceptance based on Motor Circuit Evaluation requires a signature by the NASA Construction Manager. This information should be provided along with all test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.4.5.2 Motor Current Analysis (MCA)

MCA is a method of detecting the presence of broken or cracked rotor bars or high resistance connections in end rings. Motor current spectrums in both time and frequency domains are collected with a clamp-on ammeter, normally installed at the switchgear or motor control center end, and an FFT analyzer. Rotor bar problems will appear as side bands around the power supply line frequency. MCA evaluates the amplitude of the side bands that occur about the line frequency. While MCA is an effective test on in-service motors, it is not generally used for acceptance testing. It is, however, normally performed at initial startup so a baseline can be established. This information should be provided along with all test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database.

3.4.6 Battery Impedance Testing

As the battery ages and begins to lose capacity, its internal impedance rises. This is the parameter that can be trended - comparing the current value with the original value and also with the last previous reading. Figure 3-20 shows a typical battery impedance versus age graph. The internal impedance increases as the battery ages. Additionally, if the battery has an internal short the impedance tends to go to zero; if there is an "open" the impedance will approach infinity, and premature aging due to excessive heat or discharges will cause the impedance to rise quickly.

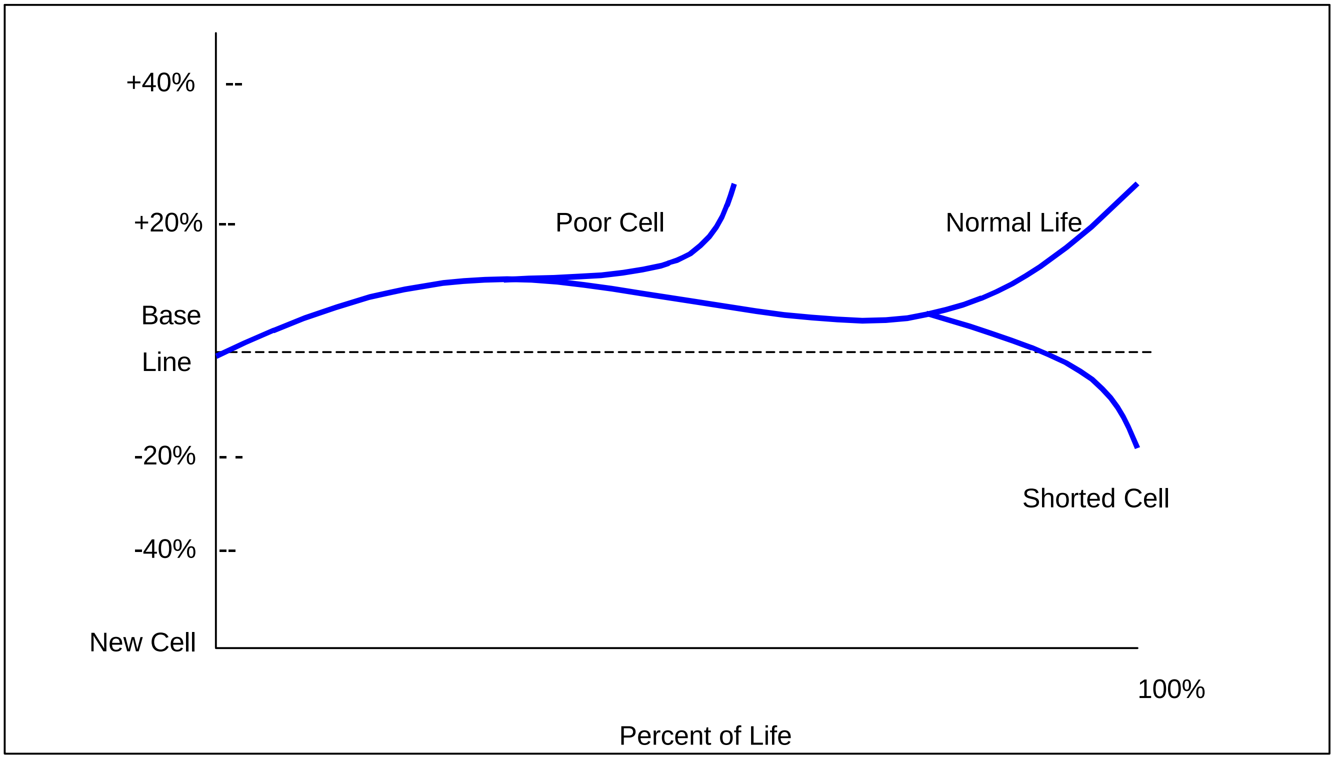


Figure 3-20. Typical Battery Impedance Versus Age

A battery impedance test set injects an AC signal between the terminals of the battery. The resulting voltage is measured and the impedance is then calculated. This measurement can be accomplished without having to remove the battery from service since the AC signal is low level and "rides" on top of the DC of the battery. Two comparisons are then made: first, the impedance is compared with the last previous reading for that battery; and, second, the reading is compared with other batteries in the same bank. Each battery should be within 10% of the others and 5% of its last reading. A reading outside of these values indicates a cell problem or capacity loss. It should be noted that there are no set guidelines and limits for this test. Each type, style, and configuration of battery will have its own impedance, so it is important to take these measurements early in a battery's life, preferably at installation. It should take less than an hour to perform this test on a battery bank of 60 cells.

Battery Impedance baseline data must be provided to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database. Defective batteries found at this time are to be replaced by the contractor prior to system acceptance.

3.4.7 Airborne Ultrasonics

Electrical arcing and discharges create sounds in the upper, or ultrasonic frequency ranges, sometimes long before a catastrophic failure occurs. Ultrasonic test devices operate in the 20kHz to 100kHz range and transpose these frequencies into the audible range so that the operator is able to hear these sounds. Corona discharges, loose switch connections, and internal arcing in deadfront electrical connections are conditions that can all be discovered using ultrasonic test devices.

These devices are very inexpensive relative to other technical testing apparatus and require very little training to operate properly. They consist of a handheld unit, or “ultrasonic gun”, attachments to concentrate the sounds, and a set of closed ear headphones. Essentially, the operator just points and listens. There are frequency settings that can be used either to tune out background frequencies or to tune in a specific frequency.

Corona discharge is normally associated with high voltage distribution systems and is produced as a result of a poor connection or insulation problem. The discharges generally occur at random, are the precursor to a failure, and are in the ultraviolet region and not normally detectable using thermography.

For switchyards the operator should use a parabolic concentrator, since the minimum distance to any live circuit will be at least 13 feet. A fixed frequency should be used to listen for a crackling sound. When inspecting electrical panels, the operator should use a rubber concentrator, a “bootie”, placed over the receiver to narrow the inspection area and help block out surrounding noises.

Airborne ultrasonics can be subjective and dependent on perceived differences in noises. To maximize the usefulness of this technology, care should be taken when setting test equipment controls for frequency ranges, sensitivity, and scale. Additionally, the operator should be cognizant of the fact that electrical loading and the presence of moisture (high humidity) may effect the ultrasonic signal.

The contractor should use airborne ultrasonics as a quality control device during construction. However, the electrical system being inspected should be loaded to at least 50%. For new or rebuilt electrical systems, an ultrasonic inspection by the appropriate maintenance organization (i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc.) should also be accomplished within 90 days of system/facility turnover. Although it is recognized that facility acceptance would have already taken place, this will allow for any initial anomalies for which the contractor is still responsible under the terms of the construction contract warranty to develop and become apparent to the inspector.

3.4.8 Non PT&I Acceptance Tests

3.4.8.1 Breaker Timing Testing

This is a mechanical test that shows the speed and position of breaker contacts before, during, and after an operation. The first timing devices were called Drop-Bar Recorders and recorded their results on a rotating drum. They were developed in the late 1930s and were the instrument of choice until the coming of rotary motion, vacuum, and high-speed breakers in the mid 1970s.

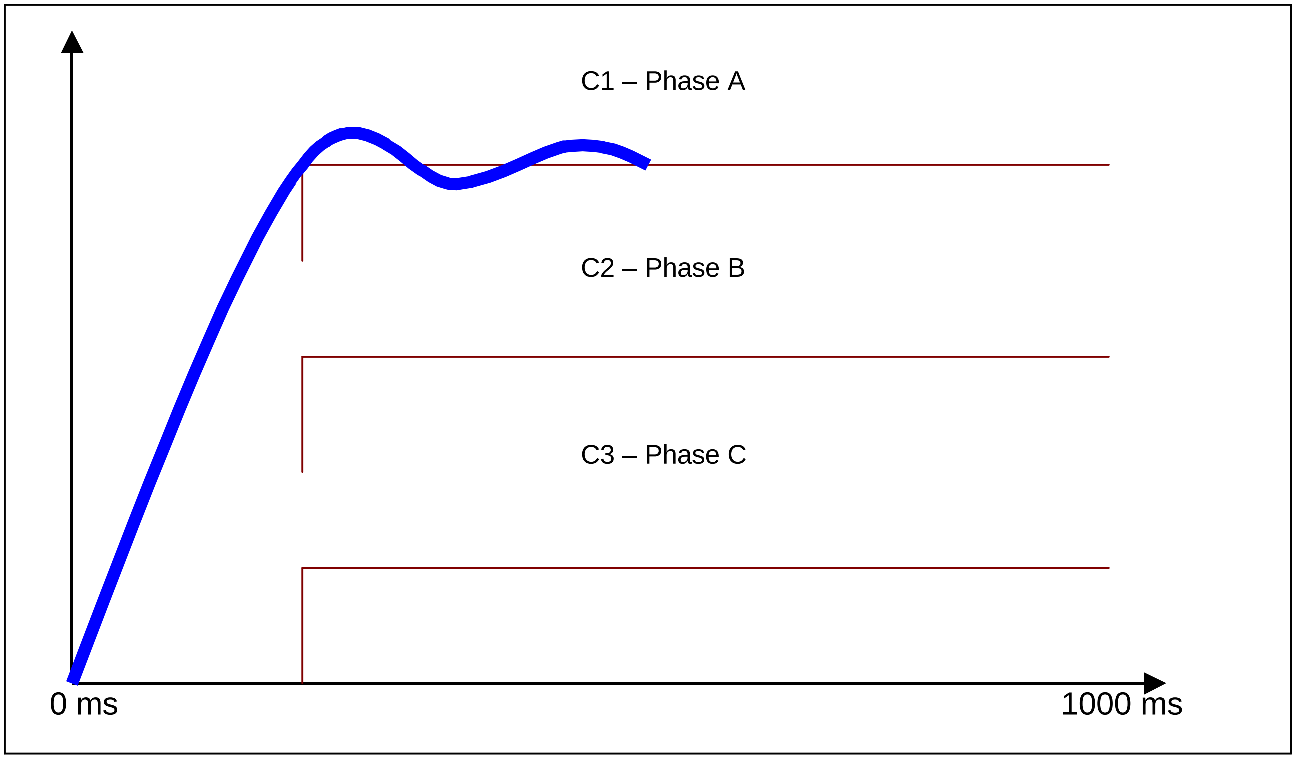


Figure 3-21. Breaker Timing Plot

In 1972 the Doble Engineering Company introduced their first breaker timer which used the light-beam recorder technology. This method used light sensitive paper that was etched using a light source and a mirror that modulated with the breaker contact travel. The main drawbacks to this technology is the fragility of the test set (mirrors go out of alignment very easily) and the amount of paper required (since the paper was etched real-time).

Today, there are two general types of timers in use - digital contact timers and digital contact and breaker travel analyzers. The digital contact timers are only good for timing contacts where no travel time is required and is really only applicable for new breakers prior to being put into service.

A digital contact and breaker analyzer measures the contact velocity, travel, overtravel, bounce back, and acceleration to give the user a good idea of the breaker operating mechanism condition. A voltage is applied to the breaker contacts, and a motion transducer is attached to the operating mechanism. The breaker is then closed and opened, and the test set measures the timeframe of voltage changes and plots the voltage changes over the motion waveform produced by the motion transducer. Figure 3-21 is an example of a motion plot. The three square waves, C1, C2, and C3 are the contacts, and the curve is the motion of the mechanism. The “wiggle” at the top of the motion waveform shows the amount of overtravel, bounce back, at seating depth of the contacts. The numbers are normally printed out from the test set, and the chart is stored in memory for downloading into a computer. This test is not applicable to molded case breakers or low voltage breakers.

Authorization for electrical system acceptance based on breaker timing testing requires a signature by the NASA Construction Manager. This information should be provided with the test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and inclusion in the maintenance database. Analyzing and trending this information will indicate if adjustments to the breaker operating mechanism are necessary.

3.4.8.2 Turns-Ratio Testing

This test measures the turns-ratio of a transformer and is mainly used as an acceptance test. It can also be used as a trouble-shooting tool when other electrical tests reveal a possible problem. During routine maintenance tests, a Turns Ratio Test (TTR) could be performed to identify short-circuited turns, incorrect tap settings, mislabeled terminals, and failure in tap changers.

To perform a turns ratio test, a voltage is applied to the primary and the induced voltage on the secondary is measured. The ratio is then calculated and compared to the nameplate data. A turns ratio measurement can show that a fault exists but can not determine the reason or location of the fault.

Because the TTR does not give information that has value for trending, and because a Power Factor Excitation test will also show a shorted turn condition, the TTR test is not an effective PT&I test for maintenance.

Authorization for electrical system acceptance based on turns ratio testing requires a signature by the NASA Construction Manager. This information should be provided by the contractor with the test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and for inclusion in the maintenance historical database.

3.4.8.3 Contact Resistance

This test is used to determine the contact condition on a breaker or switch without visual inspection. Most manufacturers of high and medium voltage circuit breakers will specify a maximum contact resistance for both new contacts and in-service contacts. The contact resistance is dependent on two things - the quality of contact area and the contact pressure. The contact quality can degrade if the breaker is called upon to open under fault conditions. The contact pressure can lessen as the breaker's springs fatigue due to age or a large number of operations.

To measure the contact resistance, a DC current, usually 10 or 100 amps, is applied through the contacts. The voltage across the contacts is measured, and the resistance is calculated using Ohms law. This value can be trended and compared with maximum limits issued by the breaker or switch manufacturer. It should be noted that for oil filled breakers, using a 100 amp test set is best because oil tends to glaze on contact surfaces and in some cases 10 amps is not enough to "punch through" the glaze.

Authorization for electrical system acceptance based on contact resistance testing requires a signature by the NASA Construction Manager. This information should be provided by the contractor with the test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and for inclusion in the maintenance database.

3.4.8.4 High Voltage Withstand Testing

High Voltage Withstand testing is a DC high voltage test that can show excessive leakage current in new and in-service equipment. It can also verify that insulation systems in new or repaired equipment can withstand designed voltage levels. Consequently, it is a good acceptance test for new and repaired electrical transmission and distribution equipment. In repaired equipment, if the leakage current continues to increase at a constant test voltage, this indicates that the repair is not to the proper standard and will probably fail soon. In new equipment, if the equipment will not withstand the appropriate test voltage, it is indicative that the insulation system or construction method is inadequate for any long term service reliability.

Authorization for electrical system acceptance based on High Voltage Withstand testing requires a signature by the NASA Construction Manager. This information should be provided by the contractor with the test data to the Construction Manager for forwarding to the appropriate maintenance organization, i.e., Systems Engineer, Condition Monitoring Office, Predictive Testing Group, etc. and for inclusion in the maintenance database.

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4. Contract Clauses and Specifications

During the procurement and construction phase of a project there are certain requirements that, when implemented properly, will allow for the necessary acceptance testing. This section contains appropriate clauses and specifications that should be used in conjunction with the parameters identified in Section 3 to order these requirements. Refer also to the *NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment* for additional procedural guidance.

4.1 Predictive Testing and Inspection (PT&I) and Acceptance Testing

4.1.1 The Contractor shall be responsible for the proper operation and installation of the facilities, systems and equipment included in this contract and for ensuring that they are free of latent manufacturing and installation defects. The contractor shall perform acceptance testing using both traditional and PT&I technologies as part of the contractor's Quality Control program throughout the installation process and immediately thereafter to verify that the installation is acceptable and to establish the required baselines for future maintenance. Not until this is complete will the equipment or facility be accepted by NASA.

4.1.2 Each machine shall have all nameplate information, all hardware and general condition noted and documented for inclusion in NASA's electronic inventory database.

4.1.3 Each contractor shall have a Quality Control plan outlining the intended methods of receiving, testing, and installing equipment. The contractor shall use trained and adequately certified personnel in the appropriate acceptance testing PT&I technologies to ensure that the results are accurate and consistent. The contractor must be in possession of the necessary test equipment.

4.1.4 Predictive Testing and Inspection (PT&I) involves the use of acceptance and inspection techniques that are non-intrusive and non-destructive in order to avoid introducing problems. It also involves the use of data collection devices, data analysis and computer databases to store and trend information. Typical PT&I technologies used during equipment acceptance include, but are not limited to, vibration analysis, oil and hydraulic fluid analysis, temperature monitoring, airborne ultrasonics, electrical system testing, and fluid flow and process analysis.

4.1.5 Preliminary and final acceptance testing and documentation of the test results, including all data, shall be performed by the contractor. The PT&I data shall be taken as part of the contractor's Quality Control Plan for equipment acceptance. NASA will observe and monitor the acceptance testing, analysis and documentation as part of NASA's Quality Assurance Program. Preliminary and final acceptance data shall be provided by the contractor to the NASA Contracting Officer. Data shall have a cover letter or sheet clearly marked with the system name, date, and the words "(Preliminary) (Final) Test

Data - Forward to the (System Engineer) (Condition Monitoring Office) (Predictive Testing Group) for inclusion in the Maintenance Information Database."

4.2 Testing and Measuring Equipment

4.2.1 General Requirements

4.2.1.1 In the 1950's acceptance testing consisted of mostly visual inspections and operational checks. However, with the onset of computers, specifically microprocessors, testing tools have been developed that can verify the minute details of an installation. Consequently, the complexity of this test equipment is such that specifying test equipment parameters is necessary to ensure that the proper data can be retrieved.

4.2.1.2 The following information shall be submitted by the contractor as part of the Quality Control Plan for all required acceptance testing:

- List of all test equipment used, including its manufacturer, model number, calibration date, certificate of calibration, and serial number.
- Certificates of test personnel qualifications and certifications.
- Proof of equivalency if the contractor desires to substitute a test requirement.

4.2.2 Vibration Monitoring

4.2.2.1 The contractor shall use a vibration data collector that has all of the following minimum requirements:

- A minimum of 400 lines of resolution
- A dynamic range greater than 70dB
- A frequency response of 5Hz-10kHz (300 to 600,000 cpm)
- The capability to perform ensemble averaging
- The use of a Hanning window
- Autoranging frequency
- A minimum amplitude accuracy over the selected frequency range of + or – 20% or + or – 1.5dB

4.2.2.2 The vibration data collector device shall use either a stud mounted or a low mass rare earth magnet mounted accelerometer. Hand-held accelerometers are not acceptable. The mass of the accelerometer and its mounting shall have minimal influence on the frequency response of the system over the selected measurement range.

4.2.2.3 The contractor shall ensure that all rotating equipment without permanent accelerometers installed have vibration monitoring disks installed using the following guideline:

- Sound discs shall be a minimum of 1 inch in diameter, manufactured of a magnetic stainless steel, such as alloy 410 or 416, have a surface finish of 32 micro-inches rms, and be attached by tack weld, be stud mounted, or be epoxy glued. The contractor shall have the option of machining the equipment case in order to achieve a flat and smooth spot that meets the same tolerances as the sound disc if the equipment case is manufactured from a magnetic material.

- Sound discs applied to components that will have permanently mounted accelerometers applied shall be drilled and tapped. The mounting hole shall be centered on the face of the disc and the disc shall have 3/8-in. available depth.
- If machined flat spots are provided, the spot area shall be free of paint, grease, or other coatings.

4.2.2.4 The contractor shall ensure that monitoring locations are positioned on structural members. The installation of sound discs on bolted cover plates or other non-rigid members are not acceptable.

4.2.2.5 Rotating equipment shall have sound disks and accelerometers installed at the following locations:

- Centrifugal Pumps, Vertically Mounted - Sound discs shall be mounted in the radial direction as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not attached to drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge, and located at the free end, at the coupled end of the motor and pump, and in the axial direction on the pump and motor, if possible.
- Centrifugal Pumps, Horizontally Mounted - Sound discs shall be mounted in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and pump as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not attached to drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge and located at the free and coupled end of the motor and pump, and in the axial direction on the motor and pump, if possible.
- Positive Displacement Pumps - Sound discs shall be mounted in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and pump as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not attached to drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge, and located at the free end, coupled end of the motor and pump, and in the axial direction on the pump and motor. An exception may be granted if the pump is sump mounted.
- Generators/Motors - The contractor shall install sound discs in the horizontal and vertical planes on the free ends of the motor- and generator-bearing assemblies. Pedestal bearings between the motor and generator should be monitored in the vertical direction radial to the shaft. Thrust bearings shall be monitored in the axial direction.
- Gearboxes - The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible.

- Compressors - The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible. Centrifugal compressors may be monitored effectively in this manner. However, reciprocating air compressors shall be monitored only for balance and alignment problems.
- Blowers and Fans - Motors on blowers and fans shall have sound discs installed in the radial and axial directions as previously described. Fan bearings shall be monitored radially in the vertical direction.
- Chillers, Centrifugal - The contractor shall mount sound discs in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and compressor as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not attached to drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the compressor discharge, and located at the free end, at the coupled end of the motor and compressor, and in the axial direction on compressor and motor.
- Chillers, Reciprocating - The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible.

4.2.3 Infrared Thermography (IRT)

The infrared imager shall be a [short wave][long wave] focal plane array camera with all of the following minimum requirements:

- Self contained with a minimum of 2 hours of battery capacity
- Temperature range of –20^{o}C to 300^{o}C
- Sensitive to 0.2^{o}C over all temperature ranges
- Accurate to within ± 3%
- Must be capable of storing up to 12 images for later use
- Have a video recorder interface

4.2.4 Insulation Power Factor

The Power Factor test set shall have all of the following minimum requirements:

- Test voltage range of 500V to 12kV
- Ability to perform UST, GST, and GST with guard tests
- Readings for power factor, dissipation factor, capacitance, and watts-loss
- Power factor/Dissipation factor range of 0 to 200%
- Capacitance measuring range of 0 to 0.20 picofarads

4.2.5 Battery Impedance

The Battery Impedance test set shall have all of the following minimum requirements:

- Ability to test battery cells of up to 2,500 amp-hour capacities
- Maximum battery test voltage of 25 Volts DC
- Impedance range of 0.0 to 100 milliohms
- Ability to test both lead-acid and nickel-cadmium batteries

4.2.6 Breaker Timing

The Breaker Timing test set shall have all of the following minimum requirements:

- Perform contact timing during breaker close, open, open-close, close-open, and open-close-open.
- Have a minimum of three dry contact inputs
- Have a minimum of two wet-input channels to monitor breaker secondary contacts
- Have a minimum resolution of ± 0.0001 seconds over a one-second duration
- Have travel transducers capable of linear and rotary motion
- Be capable of slow close contact point measurement

4.2.7 Insulation Resistance

The insulation resistance test set shall have all of the following minimum requirements:

- Test Voltage increments of 500V, 1000V, 2500V, and 5000V DC
- Resistance range of 0.0 to 500,000 megohms at 500,000V DC
- A short-circuit terminal current of at least 2.5 milliamps
- Test voltage stability of ± 0.1%
- Resistance accuracy of ± 5% at 1 megohm

4.2.7 Laser Alignment

The laser alignment system used for coupled shaft alignment shall use either a combined laser emitter and laser target detector unit or separate units for its laser emitter and laser detector targets.

4.3 Technical Manuals/Data

4.3.1 The contractor shall provide six copies, either hardcopy or electronic CD, of all pertinent operations and maintenance manuals for equipment and systems, which will include an illustrated parts breakdown, sufficiently detailed to allow NASA to obtain replacement parts when required.

4.3.2 Where available, the contractor shall provide technical manuals in electronic format. These electronic manuals shall be in Standard Graphics Markup Language. When electronic format publications are provided, only two copies of the document are required.

4.3.3 Parts breakdown shall be sufficiently detailed to allow for the identification of all replaceable parts within the equipment being procured. Cut sheets from generic catalogs are not sufficient to meet this requirement. All manuals shall be edited to limit the data to the model(s) and configuration of equipment actually delivered, including any and all options.

4.3.4 When systems are procured, the contractor shall provide technical manuals for all constituent components.

4.3.5 When measurements or surveys are required by a contract clause, the contractor shall furnish to the NASA Contracting Officer the following information concerning the equipment used to make the specified measurements:

- Test equipment - List of all test equipment used, including its manufacturer, model number, serial number, calibration date, certificate of calibration, and special personnel qualifications required.
- Equivalency - If the contractor uses an equivalent test or procedure to meet the requirements of the contract specification, the contractor shall provide to the procuring organization proof of equivalency.

4.4 Equipment Data

4.4.1 Bearings

4.4.1.1 *Drawings* - The contractor shall provide to the Contracting Officer section drawings that show, for all rotating equipment supplied under the contract, the component arrangement. The section drawings shall depict accurately the bearing support structural arrangement, be drawn to scale, and show the dimensions to the centerline of all rotating shafts.

4.4.1.2 *Bearing data* **-** The contractor shall provide to the Contracting Officer the bearing manufacturer, part number, and National Stock Number (if applicable) for all bearings used in all rotating equipment supplied under this contract. The information shall be included on the sectional drawings of each bearing location.

4.4.1.3 *Operating data* **-** The contractor shall provide to the Contracting Officer required equipment data that includes the operating speed for constant speed units and the normal operating speed range for variable-speed equipment.

4.4.2 Gearboxes

4.4.2.1 The contractor shall provide to the Contracting Officer the following information on all gearboxes supplied under the contract. This information shall be included on the sectional drawings, which must be to scale and be specific to the gear location.

- Type of gear tooth

- Gear material
- Number of teeth on each gear
- Gear ratio
- Input and output speeds

4.4.2.2 The contractor shall provide a cutaway (engineering drawing of the gearbox internal structure) so that the internal web paths to the bearings can be identified correctly.

4.4.3 Pumps

The contractor shall provide to the Contracting Officer the following information on all pumps supplied under the contract:

- Number of pump stages
- Number of pump vanes per stage
- Number of gear teeth for each pump gear
- Type of impeller or gear(s)
- Rotating speed
- Number of volutes
- Number of diffuser vanes

4.4.4 Compressors

The contractor shall provide to the Contracting Officer the following information on all compressors supplied under the contract:

- Number of compressor sections
- Number of blades per section
- Number of diffusers
- Number of vanes per diffuser
- Number of gear teeth on drive gear
- Number of driven shafts
- Number of gear teeth per driven shaft
- Rotating speed of each rotor

4.4.5 Fans

4.4.5.1 The contractor shall provide to the Contracting Officer the following information on all fans supplied under the contract:

- Type of fan or blower

- Number of rotating fan blades/vanes
- Number of stationary fan blades/vanes
- Rotating speed(s)

4.4.5.2 The contractor shall provide to the Contracting Officer the following additional information if the fans/air handlers are belt driven:

- Number of belts
- Belt lengths (measured at the pitch line)
- Diameter of the drive sheave at the drive pitch line
- Diameter of the driven sheave at the drive pitch line

4.4.5.3 For all fans supplied under the contract, the contractor shall ensure that sufficient access to the fan is present to allow for the cleaning and in-place balancing of the fan.

4.4.6 Motors

The contractor shall provide to the Contracting Officer the following information on all motors supplied under the contract:

- Bearing information required by Section 4.4.1
- Frame size
- Motor class
- Full load and locked rotor current
- Winding resistance
- Winding inductance
- Cooling fan blades
- Number of rotor bars
- Number of stator slots
- SCR firing frequencies (for variable speed and synchronous motors)

4.4.7 Transformers

The contractor shall provide to the Contracting Officer the following information on all transformers supplied under the contract:

- Winding resistances
- Current transformer ratios
- Winding insulation power factor and excitation current readings
- Bushing power factor and capacitance readings
- No-load loss at rated voltage

- Load loss at rated current
- Factory turns ratio tests
- Transformer impedance

4.4.8 Circuit Breakers

The contractor shall provide to the Contracting Officer the following information on all circuit breakers supplied under the contract:

- Required transducer for timing testing
- Maximum contact resistance
- For high-voltage bushings power factor and capacitance readings
- Breaker insulation power factor readings
- Current transformer ratios

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5. RCM Contract Clauses

There are several basic contract purposes involved in the facility and equipment life cycle. They are as follows:

- Architect/Engineering (A&E) Contracts
- Construction Contracts
- Equipment Procurement Contracts
- Maintenance and Operation Contracts

There is a need for RCM-related clauses in each of these types of contracts. Standard clauses have been developed for this purpose.

These contracts occur during the following life cycle phases:

Life Cycle Phase	**Contract Type**
Planning	None
Design	A&E
Construction	Construction
Maintenance and Operations	Equipment Procurement
	Maintenance and Operations

This chapter contains recommended standard RCM contract clauses. Clauses are grouped by equipment and the applicable technology. Tables 5-11 through 5-14 identify and cross-reference the applicability of each RCM contract clause, component, and type of contract for each phase of the contract.

The following describes the applicability of each table:

A&E Contracts	Table 5-11
Construction Contracts	Table 5-12
Equipment Procurement Contracts	Table 5-13
Maintenance and Operations Contracts	Table 5-14

The applicable RCM contract clause and criteria should be included in all Requests for Proposals (RFPs), Requests for Quotations (RFQs), and in the contracts themselves.

The clauses may be used without modification; however, they will have to be renumbered to fit the organization of the specification in which they are used.

5.1 General Contract Clauses

This section contains the standard contract clauses for all the phases in the facility life cycle. The specific clauses to be used in each phase are suggested in paragraphs 5.2 through 5.5.

For example, the vibration data listed in paragraphs 5.1.7 through 5.1.8 should be included in contract specifications if vibration analysis is to be performed as part of the RCM program.

5.1.1 Measurements and Measurement Data

When measurements or surveys are required by a contract clause, the contractor shall furnish to the procuring organization the following information concerning the equipment used to make the specified measurements:

a. **Test Equipment -** List of all test equipment used including manufacturer, model number, serial number, calibration date, certificate of calibration, and special personnel qualifications required.

b. **Equivalency -** If the contractor uses an equivalent test or procedure to meet the requirements of the contract specification, the contractor shall provide to the procuring organization proof of equivalency.

5.1.2 Bearing Information

a. **Drawings -** The contractor shall provide to the procuring organization section drawings that show the component arrangement for all rotating equipment supplied under the contract. The section drawings shall accurately depict the bearing support structural arrangement, be drawn to scale, and show the dimensions to the centerline of all rotating shafts.

b. **Bearing Data -** The contractor shall provide to the procuring organization the bearing manufacturer and part number for all bearings used in all rotating equipment supplied under this contract. The information shall be included on the sectional drawings for each bearing location.

c. **Operating Data -** The required equipment data the contractor shall provide the procuring organization under this contract shall include the operating speed for constant speed units and the normal operating speed range for variable speed equipment.

5.1.3 Gearbox Information

The contractor shall provide to the procuring organization the type and number of teeth on each gear used in the gearbox and the input and output speeds and gear ratios. This information shall be included on the sectional drawings which must be to scale and be specific to gear location.

5.1.4 Pumps

The contractor shall provide to the procuring organization the following information on all pumps supplied under the contract:

- Number of pump stages

- Number of pump vanes per stage
- Number of gear teeth for each pump gear
- Type of impeller or gear(s)
- Rotating speed
- Number of volutes
- Number of diffuser vanes

5.1.5 Centrifugal Compressors

The contractor shall provide to the procuring organization the following information on all centrifugal compressors supplied under the contract:

- Number of compressor sections
- Number of blades per section
- Number of diffusers
- Number of vanes per diffuser
- Number of gear teeth on drive gear
- Number of driven shafts
- Number of gear teeth per driven shaft
- Rotating speed of each rotor

5.1.6 Fans

The contractor shall provide to the procuring organization the following information on all fans supplied under the contract:

- Type of fan or blower
- Number of rotating fan blades/vanes
- Number of stationary fan blades/vanes
- Rotating speed(s)

The contractor shall provide to the procuring organization the following additional information if the fans/air handlers are belt driven:

- Number of belts
- Belt lengths
- Diameter of the drive sheave at the drive pitch line
- Diameter of the driven sheave at the drive pitch line

For all fans supplied under the contract, the contractor shall ensure sufficient access to the fan is present to allow for cleaning and in-place balancing of the fan.

5.1.7 Vibration Monitoring

The contractor shall provide to the procuring organization the following information for all equipment where a vibration specification is included in the contract.

5.1.7.1 Instrumentation and Sensors

The contractor shall use the type of instrumentation and sensors specified. For example, for a 3,600 RPM machine an accelerometer with a sensitivity of 100 mV/g and a resonant frequency of at least 15,000 Hz is required. A rare earth super magnet and a sound disc shall be used in conjunction with any vibration data collector which has the following characteristics:

- A minimum of 400 lines of resolution.
- A dynamic range greater than 70 dB.
- A frequency response range of 5Hz-10kHz (300-600,000 cpm).The capability to perform ensemble averaging i.e., average the data collected.
- The use of a hanning window.
- Autoranging.
- Sensor frequency response shall conform to Figure 5–1.

The contractor shall provide to the procuring organization narrowband spectral vibration data for all machines as follows:

a. For machines operating at or below 1,800 RPM, the frequency spectrum provided shall be in the range of 5 to 2,500 Hz.

b. For machines operating greater than 1,800 RPM, the frequency spectrum provided shall be in the range of 5 to 5,000 Hz.

c. Two narrowband spectra for each point shall be obtained in the following manner:

   1. For all machines regardless of operating speed, a 5 to 500 Hz spectrum with 400 lines of resolution shall be used to analyze balance, alignment, and electrical line frequency faults.

   2. An additional spectrum of 5 to 2,500 or 5 to 5,000 Hz shall be acquired for machines operating at or below 1800 RPM or greater than 1,800 RPM, respectively. This higher frequency range allows early detection of rolling element bearing, gear rotor and stator problems.

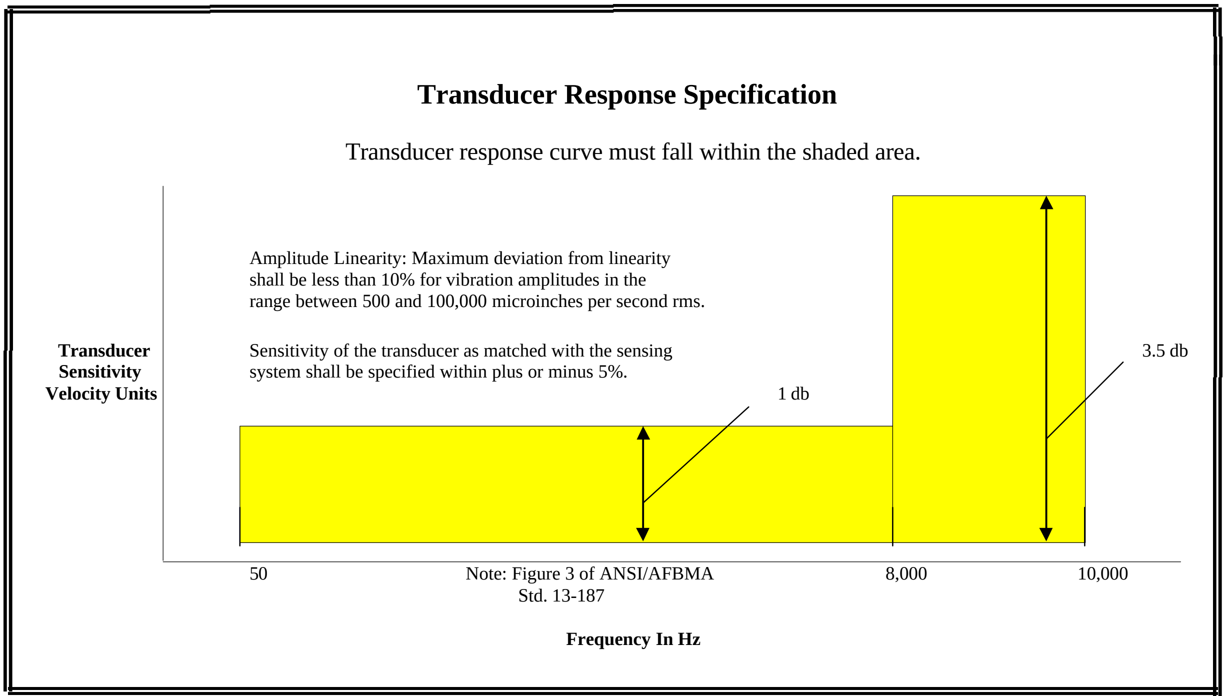

Figure 5-1. Transducer Response

3. The contractor shall report vibration data in velocity (inches/second). If proximity probes are installed, the contractor shall acquire and analyze vibration and phase data.

4. The contractor shall ensure that the equipment provided meets the following acceptable vibration amplitudes for each machine:

   (a) **Developing Vibration Criteria -** Specific vibration criteria are provided in this guide where possible. Where specific criteria are not provided the following procedure is recommended for the guide user for use in developing the vibration criteria:

      (1) Obtain nameplate data.

      (2) Obtain vibration spectra on similar machines. Differences in baseplate stiffness and mass will affect the vibration signature.

      (3) Calculate all forcing frequencies, i.e., imbalance, misalignment, bearing defect, impeller and/or vane, electrical, gear, belt, etc.

      (4) Construct a mean vibration signature for the similar machines.

      (5) Compare this mean vibration signature to the specifications and guidelines provided in this guide.

(6) Note any deviations from the guidelines and determine if the unknown frequencies are system related; e.g., a resonance frequency from piping supports.

(7) Collect vibration data on the new component at the recommended positions.

(8) Compare the vibration spectrum with the mean spectrum determined in step (5) above as well as with the criteria and guidelines provided in this guide.

(9) Any new piece of equipment should have a vibration spectrum which is no worse than a similar unit of equipment which is operating satisfactorily.

(b) **Vibration Analysis of New Equipment—**For all large or critical pieces of equipment assembled and run at the factory prior to shipment, a narrowband vibration spectrum should be acquired at the locations listed in Section 5.1.8 of this guide while the equipment is undergoing this factory performance testing. A baseline or reference spectrum should be retained for comparison with the post-installation vibration check. Equipment failing the vibration criteria should be rejected by the procuring organization prior to shipment.

Vibration tests are recommended under the following situations if the equipment fails the initial test and/or if problems are encountered following installation:

- Motor cold and uncoupled.
- Motor hot and uncoupled.
- Motor and machine coupled, unloaded and cold.
- Motor and machine coupled, unloaded and hot.
- Motor and machine coupled, loaded and cold.
- Motor and machine coupled, loaded and hot.

A significant change in the vibration signature could indicate a problem with thermal distortion and/or bearing overloading due to failure of one of the bearings to float.

(c) **Vibration Criteria for Electric Motors**

(1) General - All motor vibration spectra should be analyzed at the following forcing frequencies:

- One times running speed (1X) for imbalance.
- Two times running speed (2X) for misalignment.

- Multiples of running speed (NX) for looseness, resonance, plain bearing defects.
- Electric line frequency and harmonics (60 or 120 Hz for AC motors) for stator and rotor problems.
- The following is a list of rolling element bearing frequencies:
- Outer race defect frequency
- Inner race defect frequency
- Ball defect (ball spin frequency)
- Fundamental train frequency
- Plain or journal bearings indicate faults at harmonics of running speed and at the frequency corresponding to 0.4-0.5 of running speed.
- Other sources of vibration in motors are dependent on the number of motor rotor bars and stator slots, the number of cooling fan blades, the number of commutator bars and brushes, and on the SCR firing frequencies for variable speed motors.
- Broken rotor bars will often produce sidebands spaced at two times the slip frequency. The presence of broken rotor bars can be confirmed through the use of electrical testing.

(2) **Balance -** The vibration criteria listed in Table 5–1 are for the vibration amplitude at the fundamental rotational frequency or one times running speed (1X). This is a narrowband limit. An overall reading is not acceptable.

(3) **Additional Vibration Criteria -** All testing should be conducted at normal operating speed under full load conditions. Suggested motor vibration criteria are provided in Table 5–2. Appendix E of the *NASA RCM Guide* also contains criteria for common machines and an example of how to calculate criteria.

Motor Speed (RPM)	Maximum Vibration (in/sec, Peak)	Maximum Displacement (mils, Peak-to-Peak)
900	0.02	0.425
1200	0.026	0.425
1800	0.04	0.425
3600	0.04	0.212

Table 5–1. Motor Balance Specifications

Frequency (X RPM) Motor Component	Maximum Amplitude (in/sec Peak)
0.4 - 0.5	Not detectable
1X	See Motor Balance Specifications
2X	0.02
Harmonics (NX)	Not detectable
Roller Element Bearings	Not detectable
Side Bands	Not detectable
Rotor Bar/Stator Slot	Not detectable
Line Frequency (60 Hz)	Not detectable
2X Line Frequency (120 Hz)	0.02

Table 5–2. Motor Vibration Criteria

(4) **Rewound Electric Motors -** Due to the potential of both rotor and/or stator damage incurred during the motor rewinding process (usually resulting from the bake-out of the old insulation and subsequent distortion of the pole pieces) a rewound electrical motor should be checked both electrically and mechanically. The mechanical check consists of post-overhaul vibration measurements at the same location as for new motors. The vibration level at each measurement point should not exceed the reference spectrum for that motor by more than 10%. In addition, vibration amplitudes associated with electrical faults such as slip, rotor bar, and stator slot should be noted for any deviation from the reference spectrum.

Note: Rewinding a motor will not correct problems associated with thermal distortion of the iron.

(5) **General Equipment Vibration Standards**

- If rolling element bearings are utilized in either the driver or driven component of a unit of equipment (e.g., a pump/motor combination), no discrete bearing frequencies should be detectable. If a discrete bearing frequency is detected, the equipment should be deemed unacceptable.

- For belt-driven equipment, belt rotational frequency and harmonics should be undetectable. If belt rotation and/or harmonics are detectable, the equipment should be deemed unacceptable.

- If no specific criteria are available, the ISO 3945 acceptance Class A guidelines should be combined with the motor criteria contained in Table 5 - 2 and used as the acceptance specification for procurement and overhaul.

(6) **Specific Equipment—**Use the criteria shown in Table 5-3 on boiler feedwater, split case, and progressive cavity pumps:

Frequency Band	Maximum Vibration Amplitude (in/sec Peak)
Overall (10-1000 Hz)	0.06
1X RPM	0.05
2X RPM	0.02
Harmonics	0.01
Bearing Defect	Not detectable

Table 5–3. Pump Vibration Limits

(7) **Belt Driven Fans -** Use the criteria in Table 5-4 for belt-driven fans:

Frequency Band	Maximum Vibration Amplitude (in/sec Peak)
Overall (10-1000 Hz)	0.15
1X RPM	0.1
2X RPM	0.04
Harmonics	0.03
Belt Frequency	Not detectable
Bearing Defect	Not detectable

Table 5–4. Belt-Driven Fan Vibration Limits

(7) **Vibration Guidelines (ISO)**—Table 5–5 is based on International Standards ISO 3945 and should be used as a guideline (not as an absolute limit) for determining the acceptability of a machine for service. The vibration acceptance classes and ISO 3945 machine classes are shown in Tables 5–6 and 5–7, respectively. Note that the ISO amplitude values are overall measurements in inches/second RMS while the recommended specifications for electric motors are narrowband measurements in inches/second Peak.

5. The contractor shall collect vibration data at normal operating load, temperature, and speed.

6. The contractor shall supply all critical speed calculations. In addition, the contractor shall perform a check for machine resonance following installation and correlated with all known forcing frequencies; i.e., running speed, bearing, gear, impeller frequencies, etc.

7. The contractor shall analyze all motor vibration spectra at the following forcing frequencies and provide the results to the procuring organization:

- One times running speed (1X) for imbalance.
- Two times running speed (2X) for misalignment.
- Multiples of running speed (NX) for looseness, resonance, and plain bearing defects.

Ranges of Radial Vibration Severity			Quality Judgement for Separate Machine Classes			
Range	RMS Velocity in 10-1000 Hz at the Range Limits mm/sec	in/sec	*Class I*	*Class II*	*Class III*	*Class IV*
0.28	0.28	0.011	A	A	A	A
0.45	0.45	0.018	A	A	A	A
0.71	0.71	0.028	A	A	A	A
1.12	1.12	0.044	B	A	A	A
1.80	1.80	0.071	B	B	A	A
2.80	2.80	0.110	C	B	B	A
4.50	4.50	0.180	C	C	B	B
7.10	7.10	0.280	D	C	C	B
11.20	11.20	0.440	D	D	C	C
18	18	0.710	D	D	D	C
28	28	1.10	D	D	D	D
71	71	2.80	D	D	D	D

Table 5–5. ISO 3945 Vibration Severity Table.

- Electric line frequency and harmonics (60 or 120 Hz for AC motors) for stator and rotor problems.
- Roller element bearing frequencies, when present.

Class	Condition
A	Good
B	Satisfactory
C	Unsatisfactory
D	Unacceptable

Table 5–6. Vibration Acceptance Classes

Machine Classes for ISO 3945	
Class I	Small size machines to 20 HP
Class II	Medium size machines (20-100 HP)
Class III	Large machines (600-12,000 RPM) 400 HP and Greater Rigid mounting
Class IV	Large machines (600-12,000 RPM) 400 HP and Greater Flexible mounting

Table 5–7. Machine Classifications

5.1.8 Vibration Monitoring Locations

a. **Monitoring Discs -** For all rotating equipment provided under the contract, the contractor shall install vibration monitoring discs using the following guidelines:

1. Sound discs shall be a minimum of 1" in diameter, manufactured of a magnetic material, have a surface finish of 32 micro-inches RMS, and be attached by welding or stud mounting. The contractor has the option of machining the equipment case in order to achieve a flat and smooth spot which meets the same tolerances as the sound disc if the equipment case is manufactured from a magnetic material.

2. The contractor shall ensure monitoring locations are positioned on structural members. Installation of sound discs on bolted cover plates or other non-rigid members are not acceptable.

b. **Centrifugal Pumps, Vertically Mounted -** Sound discs shall be mounted in the radial direction as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not on drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge, and located at the free end, at the coupled end of the motor and pump, and in the axial direction on the pump and motor, if possible.

c. **Centrifugal Pumps, Horizontally Mounted -** Sound discs shall be mounted in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and pump as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not on drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge and located at the free and coupled end of the motor and pump, and in the axial direction on the motor and pump, if possible.

d. **Positive Displacement Pumps -** Sound discs shall be mounted in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and pump as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not on drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the pump discharge, and located at the free end, coupled end of the motor and pump, and in the axial direction on the pump and motor. An exception may be granted if the pump is sump mounted.

e. **Generators -** The contractor shall install sound discs in the horizontal and vertical planes on the free ends of the motor and generator bearing assemblies. Pedestal bearings between the motor and generator should be monitored in the vertical direction radial to the shaft. Thrust bearings shall be monitored in the axial direction.

f. **Gear Boxes -** The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible.

g. **Compressors -** The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible.

h. Centrifugal compressors may be monitored effectively in this manner. However, reciprocating air compressors shall only be monitored for balance and alignment problems.

i. **Blowers & Fans -** Motors on blowers and fans shall have sound discs installed in the radial and axial directions as previously described. Fan bearings shall be monitored radially in the vertical direction.

j. **Chillers**

1. **Centrifugal -** The contractor shall mount sound discs in the horizontal and vertical planes radial to the shaft at the free and coupled ends of the motor and compressor as close to the bearings as possible. Accelerometers shall be mounted to solid structures and not on drip shields or other flexible structures. Mounting locations shall be in line with each other, perpendicular to the compressor discharge, and located at the free end, at the coupled end of the motor and compressor, and in the axial direction on compressor and motor.

2. **Reciprocating -** The contractor shall install sound discs radial to the input and output shafts in the horizontal and vertical directions. Additional discs shall be installed in the axial direction as close to the input and output shafts as possible.

5.1.9 Lubricant and Wear Particle Analysis

The contractor shall provide to the procuring organization the following information on all lubricants supplied in bulk or contained within equipment supplied under this contract:

a. **Liquid Lubricants**

Viscosity grade in ISO units

AGMA and/or SAE classification as applicable

Viscosity in Saybolt Universal Seconds (SUS) or centipoise at the standard temperature and at designed normal operating temperature. The following formula should be used to calculate SUS and absolute viscosity:

$$\mathbf{Z = p_t(0.22s - 180/s)}$$

where: Z = absolute viscosity in centipoise at test temperature
s = Saybolt Universal Seconds
p_t = specific gravity at test temperature
t = temperature (deg F)

Changes in density can be calculated by the formula:

$$\mathbf{p_t = p_r - 0.00035(t-60)}$$

where: p_r = specific gravity at the reference temperature (normally 60 deg F)
t = temperature (deg F)

b. **Grease Lubricants**

National Lubrication and Grease Institute (NLGI) Number
Type and percent of thickener
Dropping point
Base oil viscosity range in SUS or centipoise
The following formula shall be used to calculate SUS and absolute viscosity:

$$\mathbf{Z = p_t(0.22s - 180/s)}$$

where: Z = absolute viscosity in centipoise at test temperature
s = Saybolt Universal Seconds
p_t = specific gravity at test temperature
t = temperature (deg F)

Changes in density can be calculated by the formula:

$$\mathbf{p_t = p_r - 0.00035(t-60)}$$

where: p_r = specific gravity at the reference temperature (normally 60 deg F)
t = temperature (deg F)

Lubricant Tests					
Test		Testing for	Indicates	Correlates with	When used
Total Acid No. (TAN) Total Base No.		pH	Degradation, oxidation, contamination	Visual, RBOT	Routine
Rotating Bomb Oxidation Test (RBOT)		Anti-oxidants remaining	Lubricant resistance to oxidation	TAN	Periodic (long term)
Solids		Solids	Contamination or degradation	TAN, RBOT, spectro-metals	Routine and post repair
Visual for color & clarity		Cloudiness or darkening	Presence of water or particulates. Oxidation of lubricant.	TAN	Routine
Spectrometals (IR spectral analysis)		Metals	Presence of contaminants, wear products and additives	Particle count	Routine
Particle count		Particles >10 m	Metal & wear product particles	Spectro-metals	Routine
Ferro-graphy	Direct	Ferrous particles up to 250 m	Wear rate	Particle count, spectro-metals	Case basis
	Analytical	Ferrous particles	Microscopic examination. Diagnostic tool.	Particle count, spectro-metals	Case basis
Micropatch		Particles, debris	Microscopic examination. Diagnostic tool	Particle count, spectro-metals, ferrography	Periodic or case basis
Water Content		Water	Degradation, leak, oxidation, emulsion	Visual, RBOT	Routine
Viscosity		Lubricating quality	Contamination, degradation	Water	Routine

Table 5–8. Lubricant Tests

c. **Lubricant Tests -** The contractor shall lubricants and perform the lubricant tests listed in Table 5–8 on all lubricants supplied by him and shall submit the results of the tests to the procuring organization.

Type of System	System Sensitivity	Suggested Maximum Particle Level (Particles per 100 milliliters)		
		5 microns	15 microns	ISO
Silt sensitive control system with very high Reliability. Laboratory or Aerospace	Super critical	4,000	250	13/9
High performance servo and high pressure long life systems. Machine tools	Critical	16,000	1,000	15/11
High quality reliable systems. General machine requirements	Very Important	32,000	4,000	16/13
General machinery and mobile systems. Med. pressure & capacity	Important	130,000	8,000	18/14
Low pressure heavy industrial systems. Long life not critical.	Average	250,000	16,000	19/15
Low pressure systems with large clearances	Main protection	1,000,000	64,000	21/17

Table 5-9. Sperry Vickers Table of Suggested Acceptable Contamination Levels for Various Hydraulic Systems

d. **Hydraulic Fluids -** All bulk and equipment-installed hydraulic fluids supplied under this contract shall meet the cleanliness guidelines in Table 5–9. The procuring organization will specify System Sensitivity. In Table 5-9, the numbers in the 5 micron and 15 micron columns are the number of particles greater than 5 microns and 15 microns in a 100-milliliter sample.

The particle counting technique utilized shall be quantitative. Patch test results are not acceptable.

The ISO numbers in the right-hand column of Table 5-9 are based on the concentration of particles greater than 5 microns and greater than 15 microns per 100-milliliter sample. The concentration can then be converted to the ISO number using an ISO Range Number Table which should be available from a hydraulic fluid vendor or lubrication laboratory.

e. **Insulating Fluids -** The contractor shall identify the type of oil used as an insulating fluid for all oil-filled transformers supplied under the contract. In addition, the contractor shall test the insulating oil using the American Society for Testing Materials (ASTM) test

Test (Units)	Silicone	Mineral	Asakrel
Dielectric Breakdown ASTM D877 (KV)	30+	30+	30+
Power Factor ASTM D924 (%)	0.01	0.05 max	0.05
Neutralization Number ASTM D974 (mg KOH/g)	<0.03	<0.03	<0.03
Interfacial Tension ASTM D2285 (dynes/cm)	N/A	35 min	N/A
Specific Gravity ASTM 1298	0.96	0.88	1.55
Flash Point ASTM D92 ©	>305	160	N/A
Fire Point ASTM D92 ©	360	177	None to Boiling
Pour Point ASTM D97 ©	-55	-51 max	-30 max
Water Content ASTM D1533 (ppm)	30 max	30 max	30 max
Viscosity at 40C ASTM D445 (SUS)	232	57.9	55.8-61.0
Color & Appearance	clear/water like	pale yellow clear	pale yellow clear

Table 5-10. Typical Properties of Transformer Oils

listed in Table 5–10 and provide the results to the Government. Any deviation from the typical properties listed below shall be corrected by the contractor before the Government will accept the transformer.

f. **Sampling Points -**The contractor shall install sampling points and lines in accordance with Method No.1 as recommended by the National Fluid Power Association (NFPA). Method No. 1 is published as NFPA T2.9.1-1972 titled Method for Extracting Fluid Samples from the Lines of an Operating Hydraulic Fluid Power System for Particulate Particle Contamination Analysis as follows:

1. **For Pressurized Systems -** A ball valve is placed in the fully opened position with a downstream capillary tube (ID> 1.25 mm) of sufficient length to reduce downstream pressure and control flow in the desired range. The sampling point shall be located in a turbulent flow region and upstream of any filters.

2. **For Reservoirs and Non-Pressurized Systems -** A 1/8" stainless steel line and ball valve is placed in the side of the oil sump or tank. The line shall be located as close to the midpoint of the structure as feasible. In addition, the sample line shall extend internally to and as close to the center of the tank as possible.

5.1.10 Thermography

a. **Electrical -** The contractor shall perform a thermographic survey on all electrical distribution equipment, motor control centers, and transformers during the start-up phase of the installation unless the thermographic survey is waived by the procuring organization.

Any defects noted by an observable difference in temperature of surveyed components or unexplained temperature rise above ambient shall be corrected by the contractor at no additional expense to the procuring organization. The contractor shall resurvey repaired areas to assure proper corrective action has been taken.

b. **Piping Insulation -** The contractor shall perform a thermographic survey on all insulated piping during the start-up phase of the installation unless the thermographic survey is waived by the procuring organization.

Any voids in the piping insulation shall be corrected by the contractor at no additional cost to the procuring organization. The contractor shall resurvey repaired areas to assure proper corrective action has been taken.

c. **Building Envelope -** The contractor shall perform a thermographic survey of the building envelope as part of the pre-beneficial occupancy to check for voids in insulation and/or the presence of wetted insulation. In addition, the presence of air gaps in building joints such as seams, door frames, window frames, etc., shall be checked via thermographic survey using an appropriate procedure and specifications described in the following:

ASTM C1060-90	*Thermographic Inspection of Insulation in Envelope Cavities In Wood Frame Buildings*.
ASTM C1153-90	*Standard Practice for the Location of Wet Insulation in Roofing Systems Using Infrared Imaging*.
ISO 6781	*Thermal Insulation-Qualitative Detection of Thermal Irregularities in Building Envelopes-Infrared Method.*
ASTM E1186-87	*Standard Practices for Air Leakage Site Detection in Buildings*.

The contractor shall clearly identify all voids or gaps noted during the thermographic scan by photographs, scale drawings, and/or by description.

For areas where the moisture content of the insulation or building envelope is questionable, the contractor shall use either destructive or non-destructive testing techniques that confirm the amount of moisture. Specific testing procedures to be used shall be proposed by the contractor and approved by the procuring organization.

d. **Boilers, Furnaces, and Ovens -** The contractor shall perform a thermographic survey during the start-up phase of installation of all furnaces, boilers, and ovens as a means of determining voids in insulation or refractory materials. Any voids detected during the survey shall be corrected by the contractor at no expense to the procuring organization.

The contractor shall perform a thermographic survey of all repaired areas prior to final acceptance by the procuring organization.

e. **Temperature Criteria -** Thermography inspections are identified as either qualitative or quantitative. The quantitative inspection is interested in the accurate measurement of the temperature of the item of interest. Quantitative inspections are rarely needed in facilities applications. The qualitative inspection is interested in relative differences, hot and cold spots, and deviations from normal or expected temperature ranges.

f. **Relative Readings -** In general, to locate abnormalities, compare similar components with similar loads. Taking relative readings on the same equipment and trending over time is also effective in detecting problems.

g. **Motors and Bearings -** Large machines should be scanned closely. Abnormal hot spots on the body may indicate flaws in the stator windings. Surface temperature of a motor is normally 7.5% lower than the winding temperature. Bearing temperatures are normally 5–20 degrees F higher than housing temperature.

h. **Power Transformers -** Abnormal heat at connections may indicate looseness, corrosion, or other flaws. Other localized heating may be indicative of flaws in windings or insufficient ventilation of the surrounding area. Temperature variations in cooling fins or tubes may indicate internal cooling problems, such as a loss of coolant or plugging. A bank of same-type transformers with significantly different temperature readings may indicate unbalanced loading or a defective transformer.

5.1.11 Airborne Ultrasonics

The contractor shall perform an airborne ultrasonic survey during the start-up phase of the installation unless the airborne ultrasonic survey is waived by the procuring organization. The contractor shall survey electrical equipment for indications of arcing or electrical discharge, including corona. Piping systems shall be surveyed for indications of leakage.

Any defects or exceptions noted by the use of airborne ultrasonics shall be corrected by the contractor at no additional expense to the procuring organization. The contractor shall re-survey repaired areas to assure proper corrective action has been taken.

5.1.12 Pulse Echo Ultrasonics

The contractor shall perform material thickness measurements on a representative sample of all material where a thickness is specified in the contract. Thickness measurements shall be performed at the fabricator’s place of business prior to shipment of any material to the project site. Material which does not meet the specified requirements of the contract shall not be shipped without the prior approval of the procuring organization.

5.1.13 Motor Circuit Analysis (Complex Phase Impedance)

Upon motor installation, the contractor shall take and provide to the procuring organization the following acceptance/baseline readings and measurements, first for the motor alone, and then, for motor and circuit together:

- Conductor path resistance

- Inductive imbalance
- Capacitance to ground

5.1.14 Motor Current Spectrum Analysis

With the motor installed and operational, the contractor shall conduct an acceptance/baseline spectral analysis on the loaded motor at 75% or greater load when specified by the procuring organization.

5.1.15 Insulation Resistance

Upon installation, the contractor shall take and provide to the procuring organization the following acceptance/baseline readings and measurements; first, for the circuit or for the motor alone, and then, for motor and circuit together:

- Polarization Index (Motors of 500 HP or more only)
- Dielectric Absorption Ratio (for all motors)
- Leakage current at test voltage

5.1.16 Surge Testing

The contractor shall perform surge testing and high potential (high-pot) resistance testing of the motor(s) prior to their installation and procuring organization acceptance. The contractor shall provide to the procuring organization documentation of test results, including test voltage, waveforms, and high potential leakage current.

5.1.17 Start-up Tests

With the motor installed and operational, the contractor shall collect and provide to the procuring organization the following baseline data:

- Coast-down time
- Peak starting current

5.1.18 Maintainability and Ease of Monitoring

The contractor shall provide for facility and equipment maintainability and ease of monitoring through design. The contractor shall provide documentation to illustrate and support the maintainability and ease of monitoring incorporated by the design.

For example, Mobile industrial equipment shall be equipped with fluid sampling ports on the engine and hydraulic systems. Accessibility to these ports shall facilitate periodic fluid sampling and system monitoring.

5.1.19 Leveling of Equipment Upon Installation

The contractor shall level all installed rotating electrical and mechanical machinery. After installation, the equipment shall not exceed a maximum slope of the base and the frame of 0.001 inch per foot. The contractor shall report to the procuring organization the type and accuracy of the instrument used for measuring the level; e.g., a 12-inch machinist's level graduated to 0.0002 inch per foot.

5.2 Architectural/Engineering (A&E) Contracts

Table 5–11 identifies the clauses that are appropriate for use in A&E contracts.

Contract Clause	Element	PT&I Technology
5.1.18	Facility	Maintainability and ease of monitoring
5.1.18	Equipment	Maintainability and ease of monitoring

Table 5–11. RCM Clauses for A&E Contracts

5.3 Construction Contracts

Contract Clause	Equipment Type	PT&I Technology
5.1.1	Measurements/surveys	N/A
5.1.2; 5.1.4; 5.1.7; 5.1.8	Pump	Vibration
5.1.9	Pump	Lubricant & wear particle analysis
5.1.2; 5.1.5; 5.1.7; 5.1.8	Compressor	Vibration
5.1.9	Compressor	Lubricant & wear particle analysis
5.1.2; 5.1.6; 5.1.7; 5.1.8	Blower/fan	Vibration
5.1.9	Blower/fan	Lubricant & wear particle analysis
5.1.2; 5.1.3; 5.1.7; 5.1.8	Gearbox	Vibration
5.1.9	Gearbox	Lubricant & wear particle analysis
5.1.10	Boiler, furnace	Infrared thermography
5.1.11	Piping	Passive ultrasound
5.1.12	Piping/pressure vessel	Pulse echo ultrasound
5.1.10	Piping insulation	Infrared thermography
5.1.10	Chiller/refrigeration	Infrared thermography
5.1.9	Chiller/refrigeration	Lubricant & wear particle analysis
5.1.2; 5.1.7; 5.1.8	Chiller/refrigeration	Vibration
5.1.11	Electrical switchgear/ circuit breakers	Passive ultrasound
5.1.10	Electrical switchgear/ circuit breakers	Infrared thermography
5.1.15	Electrical switchgear/ circuit breakers	Insulation resistance
5.1.15	Motor & Motor Circuit	Insulation resistance
5.1.13	Motor & Motor Circuit	Motor circuit analysis
5.1.14	Motor & Motor Circuit	Motor current spectrum analysis
5.1.17	Motor & Motor Circuit	Start up tests
5.1.10	Building envelope	Infrared thermography
5.1.10	Heat exchanger/condenser	Infrared thermography
5.1.11	Heat exchanger/condenser	Passive ultrasound
5.1.2; 5.1.7; 5.1.8	Electric motor	Vibration
5.1.16	Electric motor	Surge testing
5.1.2; 5.1.7; 5.1.8	Electrical generator	Vibration
5.1.13	Electrical generator	Motor circuit analysis
5.1.15	Electrical generator	Insulation resistance
5.1.10	Transformer	Infrared thermography
5.1.9	Transformer	Oil analysis
5.1.19	Rotating Equipment Elect & Mech	Equipment leveling upon installation

Table 5–12. RCM Clauses for Construction Contracts

Table 5–12 identifies the clauses that are appropriate for use in construction contracts.

5.4 Equipment Procurement Contracts

Table 5-13 identifies the clauses that are appropriate for use in equipment procurement contracts.

ContractClause	Equipment Type	PT&I Technology
5.1.2; 5.1.4; 5.1.7; 5.1.8	Pump	Vibration
5.1.9	Pump	Lubricant & wear particle analysis
5.1.2;5.1.5; 5.1.7; 5.1.8	Compressor	Vibration
5.1.9	Compressor	Lubricant & wear particle analysis
5.1.2; 5.1.6; 5.1.7; 5.1.8	Blower/fan	Vibration
5.1.9	Blower/fan	Lubricant & wear particle analysis
5.1.2; 5.1.3; 5.1.7; 5.1.8	Gearbox	Vibration
5.1.9	Gearbox	Lubricant & wear particle analysis
5.1.10	Boiler, furnace	Infrared thermography
5.1.11	Piping	Passive ultrasound
5.1.12	Piping/pressure vessel	Pulse echo ultrasound
5.1.10	Piping insulation	Infrared thermography
5.1.10	Chiller/refrigeration	Infrared thermography
5.1.9	Chiller/refrigeration	Lubricant & wear particle analysis
5.1.2; 5.1.7; 5.1.8	Chiller/refrigeration	Vibration
5.1.11	Electrical switchgear/ circuit breakers	Passive ultrasound
5.1.10	Electrical switchgear/ circuit breakers	Infrared thermography
5.1.15	Electrical switchgear/ circuit breakers	Insulation resistance
5.1.15	Motor & motor circuit	Insulation resistance
5.1.13	Motor & motor circuit	Motor circuit analysis
5.1.14	Motor & motor circuit	Motor current spectrum analysis
5.1.17	Motor & motor circuit	Start-up tests
5.1.10	Heat exchanger/condenser	Infrared thermography
5.1.11	Heat exchanger/condenser	Passive ultrasound
5.1.2; 5.1.7; 5.1.8	Electric motor	Vibration
5.1.16	Electric motor	Surge testing
5.1.2; 5.1.7; 5.1.8	Electrical generator	Vibration
5.1.13	Electrical generator	Motor circuit analysis
5.1.15	Electrical generator	Insulation resistance
5.1.10	Transformer	Infrared thermography
5.1.9	Transformer	Oil analysis
5.1.1	Measurements/surveys	N/A

Table 5–13. RCM Clauses for Equipment Procurement Contracts

5.5 Maintenance and Operations (M&O) Contracts

Table 5–14 identifies clauses that are appropriate for use in M&O contracts involving RCM.

ContractClause	Equipment Type	PT&I Technology
5.1.2; 5.1.4; 5.1.7; 5.1.8	Pump	Vibration
5.1.9	Pump	Lubricant & wear particle analysis
5.1.2; 5.1.5; 5.1.7; 5.1.8	Compressor	Vibration
5.1.9	Compressor	Lubricant & wear particle analysis
5.1.2; 5.1.6; 5.1.7; 5.1.8	Blower/fan	Vibration
5.1.9	Blower/fan	Lubricant & wear particle analysis
5.1.2; 5.1.3; 5.1.8	Gearbox	Vibration
5.1.9	Gearbox	Lubricant & wear particle analysis
5.1.10	Boiler, furnace	Infrared thermography
5.1.11	Piping	Passive ultrasound
5.1.12	Piping/pressure vessel	Pulse echo ultrasound
5.1.10	Piping insulation	Infrared thermography
5.1.10	Chiller/refrigeration	Infrared thermography
5.1.9	Chiller/refrigeration	Lubricant & wear particle analysis
5.1.2; 5.1.7; 5.1.8	Chiller/refrigeration	Vibration
5.1.11	Electrical switchgear /circuit breakers	Passive ultrasound
5.1.10	Electrical switchgear /circuit breakers	Infrared thermography
5.1.15	Electrical switchgear /circuit breakers	Insulation resistance
5.1.15	Motor & motor circuit	Insulation resistance
5.1.13	Motor & motor circuit	Motor circuit analysis
5.1.14	Motor & motor circuit	Motor current spectrum analysis
5.1.17	Motor & motor circuit	Start-up tests
5.1.10	Building envelope	Infrared thermography
5.1.10	Heat exchanger/condenser	Infrared thermography
5.1.11	Heat exchanger/condenser	Passive ultrasound
5.1.2; 5.1.7; 5.1.8	Electric motor (new and rewound)	Vibration
5.1.16	Electric motor (new and rewound)	Surge testing
5.1.2; 5.1.7; 5.1.8	Electrical generator	Vibration
5.1.13	Electrical generator	Motor circuit analysis
5.1.15	Electrical generator	Insulation resistance
5.1.10	Transformer	Infrared thermography
5.1.9	Transformer	Oil analysis
5.1.1	Measurements/surveys	N/A
5.1.19	Rotating Equipment- Electrical & Mechanical	Equipment leveling upon installation

Table 5–14. RCM Clauses for M&O Contracts

Appendix A - Resources

1. Equipment

The following is a list of manufacturers of PT&I and acceptance testing equipment and services. This list is intended to serve as a starting point only and is by no means complete, as changes in industry are occurring constantly.

Infrared Imaging

AGEMA Infrared Systems Inc.
550 County Avenue
Secaucus, NJ 07094
Phone: 201-867-5390; Fax: 201-867-2191

Computational Systems Inc. (CSI)
835 Innovation Way
Knoxville, TN. 37932
Phone: 423-675-2400; Fax: 423-675-4726
Www.compsys.com

Flir Systems (FSI)
16505 SW 72nd Ave.
Portland, OR 97224
Phone: 503-684-3731; Fax: 503-684-3207

Inframetrics Inc.
16 Esquire Road
N. Bellrica, MA 01862
Phone: 508-670-5555; Fax: 508-677-2702

Vibration Analysis, Ultrasonic, and Alignment

Bently-Nevada Corporation
1617 Water Street
Minden, Nevada 89423
Phone: 800-227-5514

Computational Systems Inc. (CSI)
835 Innovation Way
Knoxville, TN. 37932
Phone: 423-675-2400; Fax: 423-675-4726
Www.compsys.com

Entek/IRD International
1700 Edison Way
Milford, OH. 45150
Phone: 513-576-6151, Fax: 513-576-6104
www.entekird.com

Ludeca Inc.
1527 NW 89th Court
Miami, FL. 33172
Phone: 305-591-8935; Fax: 305-591-1537
Email: info@ludeca.mhs.compuserve.com

Predict/DLI
9555 Rockside Road
Cleveland, OH 44125
Phone: 800-543-8786
www.predictDLI.com

VibraMetrics
1014 Sherman Avenue
Hamden, CT. 06514
Phone: 888-225-9572
www.vibrametrics.com

UE Systems
12 W. Main St.
Elmsford, N.Y. 10523
Phone: 914-592-1220

Oil Services

Computational Systems Inc. (CSI)
835 Innovation Way
Knoxville, TN. 37932
Phone: 423-675-2400; Fax: 423-675-4726
Www.compsys.com

Insight Services
12703 Triskett Road
Cleveland, OH 44111
Phone: 800-TEST OIL
http://insight.insight.cleveland.oh.us/tribo

Predict/DLI
9555 Rockside Road
Cleveland, OH 44125
Phone: 800-543-8786
www.predictDLI.com

TriboMetrics Inc.
2475 4th Street
Berkeley, CA, 94710
Phone: 510-540-1247; Fax: 510-527-7247

Electrical Testing

AVO International
4555 Westmoreland Way
Dallas, TX. 75237
Phone: 214-330-3522; Fax: 214-333-0104
www.avo.com

Computational Systems Inc. (CSI)
835 Innovation Way
Knoxville, TN. 37932
Phone: 423-675-2400; Fax: 423-675-4726
Www.compsys.com

PdMA Corporation
5909-C Hampton Oaks Parkway
Tampa, Fl 33610
Phone: 800-476-6463
www.PdMA.com

SAVO Electronics
P.O. Box 1373
Corallis, OR 97339
Phone: 503-758-7235

2. Training & Certifications

Listed below are the organizations that offer training and certification in PT&I technologies and reliability. This list is intended to serve as a starting point only and is by no means complete, as changes in industry are occurring constantly.

AVO International Training Institute *(All Electrical Certifications)*
4555 Westmoreland Way
Dallas, TX. 75237
Phone: 214-330-3522; Fax: 214-333-0104
www.avo.com

Bently-Nevada Corporation
1617 Water Street
Minden, Nevada 89423
Phone: 800-227-5514

Computational Systems Inc. (CSI) *(Vibration I, II & III, and IRT I & II)*
835 Innovation Way
Knoxville, TN. 37932
Phone: 423-675-2400; Fax: 423-675-4726
www.compsys.com

Diagnetics Inc. *(Vibration I, II & III)*
5410 S. 94E Ave.
Tulsa, OK 74145
Phone: 800-788-9774

EPRI M&D Center *(Electrical Testing Training)*
3 Industrial Highway
Eddystone, PA 19022
Phone: 800-745-9982

Flir Systems (FSI) *(IRT level I, II & III)*
16505 SW 72nd Ave.
Portland, OR 97224
Phone: 503-684-3731; Fax: 503-684-3207

Inframetrics Inc. *(IRT level I, II & III)*
16 Esquire Road
N. Billerica, MA 01862
Phone: 508-670-5555; Fax: 508-677-2702

Ludeca Inc. *(Alignment Training)*
1527 NW 89th Court
Miami, FL. 33172
Phone: 305-591-8935; Fax: 305-591-1537
Email: info@ludeca.mhs.compuserve.com

PdMA Corporation *(Motor Testing Training)*
5909-C Hampton Oaks Parkway
Tampa, Fl 33610
Phone: 800-476-6463
www.PdMA.com

Predict/DLI *(Vibration level I, II & III, Oil and Tribology)*
9555 Rockside Road
Cleveland, OH 44125
Phone: 800-543-8786
www.predictDLI.com

Update International Inc. *(Vibration level I, II & III)*
2103 Wadsworth Blvd.
Denver, CO 80227-2400
Phone: 303-986-6761; Fax: 303-985-3950

Vibration Institute *(Vibration level I, II & III)*
6262 S. Kingery Highway, Suite 212
Willowbrook, IL 60514
Phone: 630-654-2254; Fax: 630-654-2271
www.vibinst.org

VibraMetrics, *(Vibration level I, II & III)*
1041 Sherman Ave.
Hamden, CT 06514
Phone: 800-873-6748; Fax: 203-288-4937

Appendix B - Referenced Specifications

1. Organizations

There are many technical organizations that develop standards applicable in the facilities area. Most are listed below. Standards can be researched using internet search engines. In addition, the NASA Technical Standards Program has a web page at standards.nasa.gov. At most Centers, the technical library has a subscription service that continually updates standards from the major standards organizations.

ABMA	American Bearing Manufacturers Association 1200 19th Street, NW, Suite 300 Washington, DC 20036-2422 Phone: 202-429-5155, Fax: 202-828-6042 www.abma-dc.org
ABMA	American Boiler Manufacturers Association 950 N. Glebe Rd., Suite 160 Arlington, VA 22203 Phone: 703-522-7350, Fax: 703-522-2665
AGMA	American Gear Manufacturers Association 1500 King St., Suite 201 Alexandria, VA 22314-2730 Phone: 703-684-0211, Fax: 703-684-0242 www.agma.org
AIA	Aerospace Industries Association of America 1250 Eye St. NW, Suite 1200 Washington, DC 20005 Phone: 202-371-8400, Fax: 202-371-8470 www.aia-aerospace.org
AIAA	American Institute of Aeronautics and Astronautics 1801 Alexander Bell Drive, Suite 500 Reston, VA 20191 Phone: 800-639-2422, 703-264-7500, Fax: 703/264-7657 www.aiaa.org

ANSI	American National Standards Institute 11 West 42nd Street 13th floor New York, N.Y. 10036 Phone: 212-642-4900, Fax 212-398-0023 web.ansi.org
API	American Petroleum Institute 1220 L Street, NW Washington, DC 20005 Phone: 202-682-8000 www.api.org
ARI	Air-Conditioning and Refrigeration Institute 4301 North Fairfax Drive, Suite 425 Arlington, Virginia 22203 Phone: 703-524-8800, Fax: 703-528-3816 www.ari.org
ASA	Acoustical Society of America 500 Sunnyside Blvd Woodbury, NY 11797-2999 Phone: 516-576-2360, Fax: 516-576-2377 asa.aip.org
ASCE	American Society of Civil Engineers 1801 Alexander Bell Drive Reston, Virginia 20191-4400 Phone: 703-295-6300, Fax: 703-295-6222 www.asce.org
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers 1791 Tullie Circle, N.E. Atlanta, GA 30329 Phone: 404-636-8400, Fax: 404-321-5478 www.ashrae.org
ASME	American Society of Mechanical Engineers Three Park Avenue New York, NY 10016-5990 800-843-2763 www.asme.org
ASNT	American Society for Nondestructive Testing PO Box 28518 1711 Arlingate Lane Columbus, OH 43228-0518 Phone: 800-222-2768, 614-274-6003, Fax: 614-274-6899 www.asnt.org

ASQ	American Society for Quality (formerly American Society of Quality Control) 611 East Wisconsin Avenue P.O. Box 3005 Milwaukee, WI 53201-3005 Phone: 800-248-1946, 414-272-8575, Fax: 414-272-1734 www.asqc.org
ASSE	American Society of Sanitary Engineering 28901 Clemens Road, Suite 100 Westlake, OH 44145 Phone: 440-835-3040, Fax: 440-835-3488 www.asse-plumbing.org
ASTD	American Society for Training and Development 1640 King Street PO Box 1443 Alexandria, Virginia, 22313-2043 Phone: 703-683-8100, Fax: 703-683-8103 www.astd.org
ASTM	American Society for Testing and Materials 100 Barr Harbor Drive West Conshohocken, Pennsylvania 19428-2959 Phone: 610 832-9585, Fax: 610 832-9555 www.astm.org
CGA	Compressed Gas Association 1725 Jefferson Davis Highway Suite 1004 Arlington, Virginia 22202-4102 Phone: 703-412-0900, Fax: 703-412-0128 www.cganet.com
CSI	The Construction Specifications Institute 601 Madison Street Alexandria, Virginia 22314-1791 Phone: 800-689-2900, 703-684-0300, Fax: 703-684-046 www.csinet.org
EASA	Electrical Apparatus Service Association 1331 Baur Boulevard St. Louis, Missouri 63132 Phone: 314-993-2220, Fax: 314-993-1269

IEEE	Institute of Electrical and Electronics Engineers 445 Hoes Lane, PO Box 459 Piscataway, NJ 08855-0459 Phone: 800-678-4333 www.ieee.org
IES	The Illuminating Engineering Society of North America 120 Wall Street, Fl 17 New York, NY 10005 phone: (212) 248-5000 fax: (212) 248-5017/18 www.iesna.org
ISA	Instrument Society of America 67 Alexander Drive PO Box 12277 Research Triangle Park, NC 27709 Phone: 919-549-8411, Fax: 919-549-828 www.isa.org
ISO	International Organization for Standardization 1, rue de Varembé Case postale 56 CH-1211 Genève 20 Switzerland Phone: +41 22 749 01 11, Fax: +41 22 733 34 3 www.iso.ch The US Member is the American National Standards Institute, see ANSI
NACE	National Association of Corrosion Engineers P.O. Box 218340 Houston, TX 77218 713-492-0535
NBBI	National Board of Boiler and Pressure Vessel Inspectors 1055 Crupper Avenue Columbus, Ohio 43229-1183 Phone: 614-888-8320; FAX: 614-847-5542 www.nationalboard.org
NEBB	National Environmental Balancing Bureau 8575 Grovemont Circle Gaithersburg, MD 20877 Phone: 301-977-3698 http://www.nebb.org

NEMA	National Electrical Manufactures Association 1300 North 17th Street Suite 1847 Rosslyn, VA 22209 Phone 703-841-3200, www.nema.org
NFPA	National Fire Protection Association 1 Batterymarch Park Quincy, MA 02269-9101 USA Phone: 617-770-3000, Fax: 617-770-0700 www.nfpa.org
NFPA	National Fluid Power Association 3333 N. Mayfair Road Milwaukee, WI 53222-3219 Phone: 414-778-3344, Fax: 414-778-3361 www.nfpa.com
NLGI	National Lubricating Grease Institute 4635 Wyandotte Street, Suite 202 Kansas City, Missouri, 64112-1596 Phone: 816-931-9480, Fax: 816-753-5026 www.nlgi.com
NSSB	National Skill Standards Board 1441 L Street NW Suite 9000 Washington, DC 20005 - 3512 Phone: 202-254-8628 Fax: 202-254-8646 www.nssb.org
OSHA	Occupational Safety and Health Administration U.S. Department of Labor Occupational Safety and Health Administration (OSHA) 200 Constitution Avenue, N.W. Washington, D.C. 2021 www.osha.gov
SAE	Society of Automotive Engineers 400 Commonwealth Drive Warrendale, PA 15096-0001 Phone: 724-776-4841, Fax: 724-776-576 www.sae.org
SFPE	Society of Fire Protection Engineers 7315 Wisconsin Avenue, Suite 1225W Bethesda MD 20814-0001 Phone: 301-718-2910, Fax: 301-718-2242 www.wpi.edu/Academics/Depts/Fire/SFPE

STLE	Society of Tribologists and Lubrication Engineers 840 Busse Highway Park Ridge, IL 60068-2376 Phone: 847-825-5536, Fax: 847-825-1456 www.stle.org

2. Condition Monitoring (PT&I) Information

The machinery condition monitoring technologies are being developed and refined continuously. The cost of computer systems has been a key factor in making many approaches available to monitor facilities and collateral equipment. The information provided in this section should be considered as only a starting point for researching the latest technologies and most appropriate applications.

In addition to publishing their own professional journals, many of the organizations listed below serve as clearing houses for textbooks, technical papers, presentations and other publications that are available at a reasonable cost. The magazines and groups listed below usually have advertisements and articles related to condition monitoring technologies. Some of the magazines are free to "qualified" individuals while others are only available to members.

AFE Facilities Engineering Journal
Association for Facilities Engineering (AFE)
8180 Corporate Park Drive, Suite 305
Cincinnati, OH 45242
Phone: 888-222-0155, Fax: 513-247-7422
www.afe.org

IEEE Spectrum
Institute for Electrical and Electronic Engineers (IEEE)
455 Hoes Lane
P.O. Box 459
Piscataway, N.J. 08855-0459
Phone: 800-678-4333, Fax: 723-981-9667
www.ieee.org

Maintenance Technology
Applied Technology Publications, Inc.
1300 S. Grove Ave., Suite 205
Barrington, IL 60010
Phone: 847-382-8100 Fax 847-304-8603
www.mt-online.com

Plant and Facilities Engineer's Digest
Adams/ Huebcore Publishing, Inc.
29100 Aurora Road, Suite 200
Cleveland, OH 44139
Phone: 440-248-1125, Fax: 440-248-0187
www.engineersdigest.com

P/PM Technology
SC Publishing Div.
Second Childhood Inc.
P.O. Box 2770
Minden, NV 89423
Phone: 702-267-3970

Reliability Magazine
Industrial Communications, Inc.
1704 Natalie Nehs Dr
Knoxville, TN 37931-4554
Phone: 423-531-2193/2194, Fax: 423-531-2459
www.reliability-magazine.com

Society for Machinery Failure Prevention Technology (MFPT)
4193 Sudley Road
Haymarket, VA 20169-2420
Phone: 703-754-2234, Fax: 703-754-9743
www.mfpt.org

Society for Maintenance & Reliability Professionals (SMRP)
401 N. Michigan Ave.
Chicago, IL 60611-4267
Phone: 800-950-7354 or 312-321-5190, Fax: 312-527-665
www.smrp.org

The International Society for Optical Engineering
(Thermosense Working Group)
1000 20th St.
Bellingham WA 98225-6705
Phone: 360-676-3290, Fax: 360-647-1445
www.spie.org

Vibration Institute
6262 S. Kingery Highway, Suite 212
Willowbrook, IL 60514
Phone: 630-654-2254; Fax: 630-654-227
www.vibinst.org

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Appendix C - RCM Acceptance Data Sheets

The sample RCM Acceptance Data Sheets on the following pages are provided as examples and guides for preparing similar data sheets that are customized to the specific NASA Center.

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Acceptance Data Sheet S-1
Roofing System

Type of Roofing System Installed -

Location of Installation -

Quantity of Installation -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

S-1 Roofing (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Insulation						
Type						
Location						
Layer No.						
Visual Observation						
Moisture Detected						
Damage Detected						
Voids Detected						
Infrared Image						
Moisture Detected						
Damage Detected						
Voids Detected						
IRT Image Type						
Temperature Differential						
Time of Day						
Ultrasound/Other Technology						
Moisture Detected						
Damage Detected						
Voids Detected						
Time of Day						

S-1 Roofing (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Outer Membrane						
Type						
Location						
Visual Observation						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
Infrared Image						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
IRT Image Type						
Temperature Differential						
Time of Day						
Ultrasound/Other Technology						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
Time of Day						
Flashing						
Type						
Location						
Visual Observation						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
Infrared Image						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
IRT Image Type						
Temperature Differential						
Time of Day						
Ultrasound/Other Technology						
Moisture Detected						
Damage Detected						

S-1 Roofing (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Seam Integrity/Seal						
Time of Day						
Penetrations						
Type						
Location						
Visual Observation						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
Infrared Image						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
IRT Image Type						
Temperature Differential						
Time of Day						
Ultrasound/Other Technology						
Moisture Detected						
Damage Detected						
Seam Integrity/Seal						
Time of Day						
Documentation						
Drawings						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Other						
Submitted						
90 Day Check						

Acceptance Data Sheet S-2
Insulation/ Building Envelope

Type of Insulation System/ Envelope Installed -

Location of Installation -

Quantity of Installation -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

S-2 Insulation (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Insulation						
Type						
Location						
Visual Observation						
Moisture Detected						
Damage Detected						
Voids Detected						
Infrared Image						
Moisture Detected						
Damage Detected						
Voids Detected						
IRT Image Type						
Temperature Differential						
Time of Day						
Ultrasound/Other Technology						
Moisture Detected						
Damage Detected						
Voids Detected						
Time of Day						

S-2 Insulation (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Documentation						
Drawings						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Other						
Submitted						
90 Day Check						

NOTES:

Acceptance Data Sheet S-3
Building Piping Systems

Type of Piping System Installed -

Location of Installation -

Quantity of Installation -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

S-3 Piping (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Piping						
Type						
Location						
Size						
Length						
Fluid						
Capacity						
Flow						
Visual Observation						
Joint Integrity						
Damage Detected						
Leaks Detected						
Solenoid Valve						
Expansion Valve						
Isolation Valve						
Relief Valve						
Control Valve						
Pressure Test						
Leak Test Pressure						

S-3 Piping (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Hydro Test						
Leak Test Pressure						
Ultrasound Test						
Joint Integrity						
Valves						
Fittings						
Leaks Detected						
Steam Traps						
Identification/location						
Operational (Y/N)						
Infrared Inspection						
Insulation Integrity						
Fluid Flow						
Adequate						
Restricted						
Documentation						
Drawings						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Other						
Submitted						
90 Day Check						

Acceptance Data Sheet M-1
Pumps

Pump Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-1 Pumps (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Pump						
Type						
Location						
Number of stages						
Number of Vanes per stage						
No. gear teeth/ each pump gear						
Type of impeller or gear						
Rotating speed						
No. of volutes						
No. of Diffuser vanes						
Visual Observation						
Leaks Detected						
Non-cavitating, Non-separating						
No piping strain						
Shaft coupling aligned						
Meets straight run standard						
Vibration Analysis						
Test Instrumentation						

M-1 Pumps (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
FFT Analyzer						
Type						
Model						
Ser #						
Last calibration date						
Line Resolution Bandwidth						
Dynamic Range						
Hanning window						
Linear Non-overlap Averaging						
Antiliasing Filters						
Amplitude Accuracy						
Sound disk thickness						
Adhesive (hard/soft)						
Vibration Readings (locations)						
1H						
1V						
1A						
2H						
2V						
2H						
Velocity Amplitude (in/sec-peak)						
Running Speed Order						
Frequency (CPM)						
Balanced Condition?						
Pumping Frequency						
Pumping Band						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						

M-1 Pumps (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet M-2
Gearboxes

Gearbox Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-2 Gearboxes (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Gearbox						
Type						
Location						
Visual Observation						
Vibration Analysis						
Test Instrumentation						
FFT Analyzer						
Type						
Model						
Ser #						
Last calibration date						
Line Resolution Bandwidth						
Dynamic Range						
Hanning window						

M-2 Gearboxes (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Linear Non-overlap Averaging						
Antiliasing Filters						
Amplitude Accuracy						
Sound disk thickness						
Adhesive (hard/soft)						
Vibration Readings (locations)						
1H						
1V						
1A						
2H						
2V						
2H						
Velocity Amplitude (in/sec-peak)						
Frequency Band (in Orders)						
Vibration Envelope						
Hydraulic Oil						
System Sensitivity						
Actual Particle Level (part/100ml)						
Particle Level Tolerance (T 3-3)						
Lubrication Oils						
Liquids						
Viscosity Grade (ISO Units)						
AGMA/SAE classification						
Additives						
Grease						
Type of base stock						
NLGI Number						
Type/% of thickener						
Dropping Point						
Base oil viscosity (SUS)						
Total Acid Number						
Total Acid Number Limit						
Visual Observation (Cloudiness)						
Visual Cloudiness Limit						

M-2 Gearboxes (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
IR Spectral Analysis - metal count						
IR Spectral Analysis Limit						
Particle Count						
Particle Count Limit						
Water Content						
Water Content Limit						
Viscosity						
Viscosity Limit						
Documentation						
Layout Drawings						
Sectional Drawings						
Type of gear tooth						
Gear Material						
Number of Teeth/gear						
Gear Ratio						
Input and Output Speeds						
Cutaway of Internal Structure						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet M-3
Rotating Machinery

Machine Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-3 Rotating Machine (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Machine						
Type						
Location						
Compressor						
No. compressor sections						
No. blades/section						
No. diffusers						
No. vanes/diffuser						
No. gear teeth on drive gear						
No. driven shafts						
No. gear teeth/driven shaft						
Rotating speed/rotor						
Fan						
Type fan or blower						
No. rotating blades/vanes						
No. stationary blades/vanes						
Rotating speeds						
No. belts						
Belt lengths						
Diameter of drive sheave						
Diameter of driven sheave						

M-3 Rotating Machine (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Visual Observation						
Vibration Analysis						
Test Instrumentation						
FFT Analyzer						
Type						
Model						
Ser #						
Last calibration date						
Line Resolution Bandwidth						
Dynamic Range						
Hanning window						
Linear Non-overlap Averaging						
Antiliasing Filters						
Amplitude Accuracy						
Sound disk thickness						
Adhesive (hard/soft)						
Vibration Readings (locations)						
1H						
1V						
1A						
2H						
2V						
2H						
Velocity Amplitude (in/sec-peak)						
Running Speed Order						
Frequency (CPM)						
Balanced Condition?						
Balance Wt. Type						

M-3 Rotating Machine (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Keyed shaft?						
Key length A (Fig 3-13)						
Key length B (Fig 3-13)						
Final Key length (Fig 3-13)						
Alignment						
RPM						
Soft Foot Actual (in) (Table 3-2)						
Soft Foot Tolerance (Table 3-2)						
Vert angularity at coupling- Actual						
Vert angularity Tolerance						
Vert offset at coupling-Actual						
Vert offset Tolerance						
Horiz angularity at coupling-Act'l						
Horiz angularity Tolerance						
Horiz offset at coupling-Actual						
Horiz offset Tolerance						
Axial Shaft Play						
Shims						
Shim type						
Shim condition						
Number of shims in pack						
Thickness						
Sheaves						
True to shaft						
Runout (in.)						
Hydraulic Oil						
System Sensitivity						
Actual Particle Level (part/100ml)						
Particle Level Tolerance (T 3-3)						
Lubrication Oils						
Liquids						
Viscosity Grade (ISO Units)						
AGMA/SAE classification						

M-3 Rotating Machine (Sheet 4) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Additives						
Grease						
Type of base stock						
NLGI Number						
Type/% of thickener						
Dropping Point						
Base oil viscosity (SUS)						
Total Acid Number						
Total Acid Number Limit						
Visual Observation (Cloudiness)						
Visual Cloudiness Limit						
IR Spectral Analysis - metal count						
IR Spectral Analysis Limit						
Particle Count						
Particle Count Limit						
Water Content						
Water Content Limit						
Viscosity						
Viscosity Limit						
Documentation						
Layout Drawings						
Bearing Layout						
Bearing Data						
Operating Data (speed, etc)						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet M-4
Heat Exchangers

Heat Exchanger Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-4 Heat Exchangers (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Heat Exchanger						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Warble Tone Generator						
Differential Pressure Method						
Results:						

M-4 Heat Exchangers (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet M-5
Boilers

Boiler Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-5 Boilers (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Boiler						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Contact Probe						
Results:						

M-5 Boilers (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet M-6
Steam Traps

Steam Trap Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

M-6 Steam Traps (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Steam Trap						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Contact Probe						
Results:						

M-6 Steam Traps (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet E-1
Transformers

Transformer Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-1 Transformers (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Transformer						
Type						
Location						
Winding resistance						
Current transformer ratio						
Winding insulation power factor						
Winding excitation current						
Bushing power factor						
Bushing capacitance						
No-load loss at rated voltage						
Loss load at rated current						
Factory turns ratio test results						
Transformer impedance						
Current Loading						
Visual Observation						

E-1 Transformers (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
IRT Test Kit						
Sensitivity						
Accuracy						
Transformer Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Power Factor Test						
Grounded Specimen Test -GST						
Ungrounded Specimen Test -UST						
GST with Guard						
High Voltage Windings						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Low Voltage Windings						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Environment Humidity						
Environment Temperature						
Surface Cleanliness						

E-1 Transformers (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Minimum Resistance Value						
Airborne Ultrasonics						
Frequency Range Set						
Sensitivity Level Set						
Scale Set						
System Loading (%)						
Results:						
Insulation Oil Test (limits in ( ))						
Dissolved Gas Analysis						
Nitrogen (N_2) (<100 ppm)						
Oxygen (O_2) (<10 ppm)						
Carbon Dioxide (CO_2) (<10 ppm)						
Carbon Monoxide (CO)(<100ppm)						
Methane (CH_4) (none)						
Ethane (C_2H_6) (none)						
Ethylene (C_2H_4) (none)						
Hydrogen (H_2) (none)						
Acetylene (C_2H_2) (none)						

E-1 Transformers (Sheet 4) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Karl Fisher (<25 ppm @ 20degC)						
Dielectric Breakdn Strngth (>30kV)						
Neutralization Number (<.05mg/g)						
Interfacial Tension (>40dynes/cm)						
Color (<3.0 - ASTM D-1524)						
Sediment (clean)						
Power Factor (<.05%)						
Visual Examination (clear)						
Turns Ratio test						
Voltage Applied (applied)						
Induced Voltage (secondary)						
Calculated Ratio						
Nameplate Data Ratio						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet E-2
Circuit Breakers

Circuit Breaker Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-2 Circuit Breakers (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Circuit Breaker						
Type						
Location						
Visual Observation						

E-2 Circuit Breakers (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Airborne Ultrasonics						
Frequency Range Set						
Sensitivity Level Set						
Scale Set						
System Loading (%)						
Results:						
IRT Test Kit						
Sensitivity						
Accuracy						
Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Power Factor Test						
Grounded Specimen Test -GST						
Ungrounded Specimen Test -UST						
GST with Guard						
Open Position						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Closed Position						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						

E-2 Circuit Breakers (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Bushings						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Environment Humidity						
Environment Temperature						
Surface Cleanliness						
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Insulation Oil Test (limits in ( ))						
Dissolved Gas Analysis						
Nitrogen (N_2) (<100 ppm)						
Oxygen (O_2) (<10 ppm)						
Carbon Dioxide (CO_2) (<10 ppm)						
Carbon Monoxide (CO)(<100ppm)						
Methane (CH_4) (none)						
Ethane (C_2H_6) (none)						
Ethylene (C_2H_4) (none)						
Hydrogen (H_2) (none)						
Acetylene (C_2H_2) (none)						

E-2 Circuit Breakers (Sheet 4) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Karl Fisher (<25ppm@20degC)						
Dielectric Breakdn Strngth (>30kV)						
Neutralization Number (<.05mg/g)						
Visual Examination (clear)						
Breaker Timing						
Voltage applied						
C1 - Phase A						
C2 - Phase B						
C3 - Phase C						
Contact Resistance						
DC Current applied						
Measured Voltage						
Calculated Resistance						
Manufacturer Resistance						
High Voltage Testing						
DC High Voltage Applied						
Leakage Current						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet E-3
Electric Motors

Motor Nameplate Data -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-3 Electric Motors (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Motor						
Type						
Location						
Bearing Information						
Frame size						
Motor class						
Full load and locked rotor current						
Winding Resistance						
Winding Inductance						
Cooling fan blades						
No. rotor bars						
No. stator slots						
SCR firing sequence						
Visual Observation						
Leaks Detected						

E-3 Electric Motors (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Vibration Analysis						
Test Instrumentation						
FFT Analyzer						
Type						
Model						
Ser #						
Last calibration date						
Line Resolution Bandwidth						
Dynamic Range						
Hanning window						
Linear Non-overlap Averaging						
Antiliasing Filters						
Amplitude Accuracy						
Sound disk thickness						
Adhesive (hard/soft)						
Vibration Readings (locations)						
1H						
1V						
1A						
2H						
2V						
2H						
Velocity Amplitude (in/sec-peak)						
Acceleration Overall Amp (g-peak)						
Vibration Signatures (H,V,A)						
Frequency (CPM)						
Balanced Condition?						
Current Loading						
IRT Test Kit						
Sensitivity						
Accuracy						
Transformer Criticality						
Actual Temperature Read						

E-3 Electric Motors (Sheet 4) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Reference Normal Temperature						
Power Factor Test						
Grounded Specimen Test -GST						
Ungrounded Specimen Test -UST						
GST with Guard						
Phase I						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Phase II						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Phase III						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Environment Humidity						
Environment Temperature						
Surface Cleanliness						

E-3 Electric Motors (Sheet 5) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Insulation Resistance Test						
Phase I						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Phase II						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Phase III						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Motor Circuit Evaluation						
Resistance						
Resistance Imbalance (<2%)						
Inductance						
Inductance Imbalance (<10%)						
Capacitance						
Total Impedance						
Impedance Imbalance						

E-3 Electric Motors (Sheet 6) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Motor Current Analysis						
High Voltage Testing						
DC High Voltage Applied						
Leakage Current						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet E-4
Batteries

Battery Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-4 Batteries (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Battery						
Type						
Location						
Visual Observation						
Current Loading						
IRT Test Kit						
Sensitivity						
Accuracy						

E-4 Batteries (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Battery Impedance testing						
Battery Age						
Applied Voltage						
Read Voltage						
Delta						
Impedance						
Compare vs Previous Reading (<5% difference)						
Compare vs Similar Batteries (<10% difference)						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet E-5
Motor Control Centers

Motor Control Center Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E5 Motor Control Cntrs (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Motor Control Center						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Frequency Range Set						
Sensitivity Level Set						
Scale Set						
System Loading (%)						
Results:						

E5 Motor Control Cntrs (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Current Loading						
IRT Test Kit						
Sensitivity						
Accuracy						
Transformer Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet E-6
Switchgear

Switchgear Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-6 Switchgear (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Switchgear						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Frequency Range Set						
Sensitivity Level Set						
Scale Set						
System Loading (%)						
Results:						

E-6 Switchgear (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Current Loading						
IRT Test Kit						
Sensitivity						
Accuracy						
Transformer Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Power Factor Test						
Grounded Specimen Test -GST						
Ungrounded Specimen Test -UST						
GST with Guard						
Buss						
Voltage Rating (V)						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-7)						
Environment Humidity						
Environment Temperature						
Surface Cleanliness						
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						

E-6 Switchgear (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Contact Resistance						
DC Current applied						
Measured Voltage						
Calculated Resistance						
Manufacturer Resistance						
High Voltage Testing						
DC High Voltage Applied						
Leakage Current						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Acceptance Data Sheet E-7
Power Panels

Power Panel Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-7 Power Panels (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Power Panel						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Frequency Range Set						
Sensitivity Level Set						
Scale Set						
System Loading (%)						
Results:						

E-7 Power Panels (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Current Loading						
IRT Test Kit						
Sensitivity						
Accuracy						
Transformer Criticality						
Actual Temperature Read						
Reference Normal Temperature						
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						
Vibration Data						
Certification						
Other						
Submitted						

Acceptance Data Sheet E-8
Power Cables

Power Cable Identification -

Location of Installation -

NASA ID Number -

Date(s) Installed -

Reference Drawing Numbers -

Test Equipment Identification -

E-8 Power cables (Sheet 1) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Power Cable						
Type						
Location						
Visual Observation						
Airborne Ultrasonics						
Contact Probe						
Results:						

E-8 Power cables (Sheet 2) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Power Factor Test						
Grounded Specimen Test -GST						
Ungrounded Specimen Test -UST						
GST with Guard						
Applied Voltage						
Total Current						
Resistive Current						
Capacitive Current						
Dissipation Factor						
Power Factor						
Normal Power Factor (Table 3-8)						
Environment Humidity						
Environment Temperature						
Surface Cleanliness						
Insulation Resistance Test						
Capacitance Charging Current						
Dielectric Absorption Current						
Leakage Current						
Temperature Correction Factor						
Polarization Index						
Dielectric Absorption Ratio						
High Voltage Testing						
DC High Voltage Applied						
Leakage Current						
Documentation						
Layout Drawings						
Test Point Locations						
Manufacturer Data						
Maintenance Manual						
Warranty						
ID of Materials and Location						
Signatures						

E-8 Power cables (Sheet 3) Design Criteria/ Location	Date of Inspection	Specified	Submitted	Tested	Accepted	Comments
Vibration Data						
Certification						
Other						
Submitted						

NOTES:

Appendix D—SPECSINTACT CLAUSES WITH RCM APPLICATIONS

The following table includes reference numbers, titles, and general RCM application descriptions for clauses where RCM principles have been integrated into the SPECSINTACT. They can be used as a ready reference to access SPECSINTACT for more detail.

Clause	Title	General RCM Application
Division I	General Requirements	
01450	Quality Control	
1.4.4.2	Inspection and Test Records	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
01600	Product Requirements	
2.1	Mechanical Materials and Equipment	Material “cut sheets” and final test data to be forwarded to CM Office/PT&I Group for inclusion in Maintenance database
01750	Starting and Adjusting	
1.3.1	Tests Required	Tests are to be performed on systems including electrical switchgear, protective relaying, fluid and gas systems, pump/motor combinations, boiler systems, hydraulic and pneumatic control, condition/performance monitoring systems, energy control and monitoring systems and other assemblies and components that need to be tested as an interrelated whole.
1.3.2	Factory Tests	Tests shall be performed by the factory to verify proper build. These test results will be used in the "Final Acceptance Test" section to verify no shipping damage and proper installation.
1.3.4	Final Acceptance Test	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
01780	Closeout Submittals	
1.3	Submittals	Preventative Maintenance and Condition Monitoring (Predictive Testing) and Inspection schedules shall be submitted by the Contractor with instructions that state when systems should be retested.
Division II	Site Work	
02535	Packaged Lift Stations	
1.2	Submittals	Bearings shall be included in manufacturer's catalog data. Preventative Maintenance, Predictive Testing and Inspection procedures for Package Lift Stations shall be submitted. Procedures should include frequency of preventative maintenance, frequency of predictive testing and inspection, adjustment, lubrication, and cleaning necessary to minimize corrective maintenance and repair.

Clause	Title	General RCM Application
2.11	Balance	Allowable vibration limits shall be in accordance with ISO 1940/1, Table 1.
2.12	Shafts	NOTE: When possible, specify sealed bearings on motors. When properly installed sealed bearings have as long a life as conventional bearings, with almost no maintenance requirements.
2.14	Lubrication	Bearings on vertical-shaft pumps shall be self lubricating, permanently sealed.
Division VII	Thermal & Moisture Protection	
07210	Building Insulation	
3.10.1	Finished-Building Insulation	Following a minimum of 90 days operation (or installation), but no later than one year, the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping.
07220	Roof and Deck Insulation	
3.3.5	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer Systems Engineer/ Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
07510	Built-up Bituminous Roofing	
3.4.3	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer Systems Engineer/ Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
07511	Built-up Asphalt Roofing	
3.4.11	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer Systems Engineer/ Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
07530	Single Ply Membrane Roofing	

Clause	Title	General RCM Application
3.9	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer.
Division IX	Finishes	
09915	Painting	
---	Intro Note	For harsh indoor environments (any area subjected to chemical and/or abrasive action), and all outdoor installations, reference Section 09960, "High Performance Coatings."
09960	High Performance Coatings	
---	Intro Note	This section covers special coatings as required for harsh indoor locations or operations (any area subjected to chemical and/or abrasive action), and all outdoor installations.
2.2	Epoxy Coatings	Epoxy resin coatings must be used where surfaces to be coated require high corrosion resistance, chemical resistance, bond strength, UV resistance, and toughness.
2.3	Polyurethane Coatings	Polyurethane-based coatings must be used where surfaces to be coated require high abrasion resistance, good flexibility and chemical resistance, UV resistance, and must be a two-part, prepolymer, catalytic-cured resin material
Division XIII	Special Construction	
13960	Carbon Dioxide Extinguishing Systems	
3.2.1	Preliminary Tests	Storage batteries shall be given an impedance test of each cell and the results recorded to be used as baselines. Final Test Reports shall be forwarded to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
Division IXV	Conveying Systems	
14210	Electric Traction Elevators	
2.3.2	Gears and Bearings	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
2.3.5	Hoist Motor	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.

Clause	Title	General RCM Application
2.4	Motor-Generator Set	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
14240	Hydraulic Elevators	
1.2	Submittals	Submitted test results shall include Hydraulic oil purity tests results.
2.2	Pump	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
2.3	Motor	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
3.2.2	Tests	Hydraulic oil purity test should include measurement of viscosity and ferrographic analysis to insure the oil is free from contaminates.
14600	Hoists and Cranes	
1.9.5	Bearings and Bearing Life	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
2.5.8	Motor Bearings	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
2.5.12	Motor Controller	Ability to open and/or remove access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
3.8	Crane Electrification System Factory Tests	Certification test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
3.9	On-Site Complex Electrification System Tests	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
14920	Monorail System	
2.16.4	Hoist Motors	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.

Clause	Title	General RCM Application
2.16.6	Motor Bearings	When possible the use of sealed bearings is encouraged. One of the major causes of bearing failures is over lubrication and lubrication contamination. Using sealed bearings helps to eliminate this failure mode.
2.16.7	Motor Controller	NOTE: Ability to open and/or remove access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
Division XV	Mechanical	
15003	General Mechanical Provisions	
1.7	Prevention Of Corrosion	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
2.4	Painting	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.1	Installation	No installation shall be permitted which blocks or otherwise impedes access to any existing machine or system. Except as otherwise indicated, emergency switches and alarms shall be installed in conspicuous locations. All indicators, to include gauges, meters, and alarms shall be mounted in order to be easily visible by people in the area.
3.2	Equipment Pads	Equipment bases and foundations, when constructed of concrete or grout, shall cure a minimum of 28 or 14 days as specified before being loaded.
15083	Duct Insulation	
3.1	Installation of Insulation Systems	Insulation shall not impede access to duct covers/doors used for duct cleaning and/or maintenance.
3.3	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database..
15085	Piping Insulation	

Clause	Title	General RCM Application
3.3	Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic mapping. Final acceptance will also depend upon providing construction (as built) details to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database..
15135	Centrifugal Pumps	
2.1.5	Balancing	Pump impeller assemblies shall be statically and dynamically balanced to ISO 1940/1-1986, G6.3, G2.5, or G1.0 as specified.
2.1.11	Bearings and Lubrication	Double-row ball or roller bearings for engineered-quality pumps shall shall have an L-10 rated life of not less than 30,000, 50,000, or 80,000 hours as specified. Bearings shall be permanently lubricated sealed bearings.
2.2.4	Balancing	Pump impeller assemblies shall be statically and dynamically balanced to ISO 1940/1-1986, G6.3, G2.5, or G1.0 as specified.
2.2.9	Bearings And Lubrication	Bearings shall be heavy-duty ball or roller type and shall have an L-10 rated life of not less than 30,000, 50,000, or 80,000 hours as specified. Bearings shall be permanently lubricated sealed bearings.
3.2	Grouting	Grout shall cure a minimum of 28 days or as specified before being loaded.
3.4	Alignment	Provides pump and driver minimum alignment specifications and doweling requirements.
3.6	Pump Acceptance	Prior to pump final acceptance vibration analysis shall verify pump conformance to specifications. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15186	Condensate Pumps	
1.2	Submittals	Test Reports for condensate pumps shall consist of Pump Flow Capacity Tests in accordance with the paragraph entitled, "Testing," of this section, Efficiency Tests and Vibration Tests.
2.1.1	Pumps	When pump is operating at its worst hydraulic condition vibration readings shall conform to ISO 1940/1, G6.3, G2.5, or G1.0 as specified.
3.1	Installation	Pump and driver alignment specifications are given based on the motor nominal operating speed.

Clause	Title	General RCM Application
3.2.2	Acceptance Testing	Pump shall be operated and the demonstration shall verify that the pump is non-over loading at any operating point and that the flow capacity is as specified. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/ Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15445	Sump Pumps	
2	Products	Pump and Motor vibration levels shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted.
2.1.6	Bearings and Lubrication	Bearings shall be sealed and grease-lubricated and shall have an L-10 rating of not less than 80,000 hours in accordance with AFBMA 9 or AFBMA 11.
3.1.1	Alignment	
3.2.2	Pump Acceptance	Prior to final acceptance, pump conformance to manufacturer's specifications shall be demonstrated by checking vibration with specified vibrometer while the pump is operating against shutoff head, i.e., with discharge valve closed. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15510	Boilers	
3.4	Final Acceptance	Following a minimum of 90 days operation (or installation), but no later than one year (but prior to the warranty expiration date), the Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation using advanced monitoring technologies such as Infrared Imaging or Ultrasonic detection. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15610	Refrigeration Compressors	
2	Products	Pump and Motor vibration levels shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted.
2.1.2	Compressor	Rotating parts shall be statically and dynamically balanced at the factory to ISO 1940/1 1986, G6.3, G2.5, or G1.0 as specified to eliminate vibration.

Clause	Title	General RCM Application
3.2.1	Vibration	Specifies the type and characteristics of the vibration analyzer the Contractor shall use. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15625	Chilled Water Air Conditioning	
2.2.1	Centrifugal Fan	Fan and Motor balance shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted. When possible the use of sealed bearings is encouraged. Fans driven by motors rated over 7.5 HP [5.6 KW] shall be furnished with access doors and other provisions necessary to permit field balancing of the rotating elements, addition of corrective weights, and measurement of residual unbalance. Bearings shall have an L-10 rated life of not less than 30,000, 50,000 or 80,000 hours as specified in accordance with AFBMA 9 or AFBMA 11. Removable metal guard and adjustable rail specifications are provided.
2.2.5	Electrical Requirements	Ability to open and/or remove access covers is required for maintenance activities.
3.8	Acceptance Tests	Specifies the type and characteristics of the vibration analyzer the Contractor shall use. Final test reports shall be provided to the Contracting Officer and forwarded to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15626	Centrifugal Water Chillers	
2	Products	Provides pump and motor balance and vibration level specifications.
2.2	Compressor	Rotor assembly shall be statically and dynamically balanced to ISO 1941/1-1986, G6.3, G2.5, or G1.0 as specified.
2.7	Motors	Hermetically sealed motors shall conform to NEMA MG-1, ARI 520 and to requirements for motors as specified. Bearings shall be oil-lubricated, replaceable-sleeve, insertable type permanently lubricated, rolling element type.
3.4	Alignment	Provides pump and driver alignment specifications.
3.5	Field Testing	Prior to final acceptance, vibration analysis shall verify pump and motor conformance to specifications. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15627	Reciprocating Water Chillers	
2	Products	Provides pump and motor balance and vibration level specifications.
2.3.1	Compressor	Rotating parts shall be statically and dynamically balanced to ISO 1940/1-1986, G16, or G6.3 as specified.

Clause	Title	General RCM Application
15675	Air-cooled Condensers	
2	Products	Provides pump and motor balance and vibration level specifications.
2.2	Fans and Drives	Fans shall be statically and dynamically balanced to ISO 1940/1-1986, G6.3 or G2.5 as specified. Bearings shall be permanently lubricated sealed bearings.
15700	HVAC Systems	
2	Products	Provides pump and motor balance and vibration level specifications.
2.7	Insulation	Insulation shall not impede access to duct covers/door used for duct cleaning and/or maintenance.
2.11.3.1	Fans and Drives	Fans shall be statically and dynamically balanced to ISO 1940/1 1986, G6.3, G2,5,or G1,0 as specified. Bearings shall be sealed against moisture and dirt, prelubricated, and suitable for not less than 10,000 operating hours without need of re-lubrication. Bearings shall be permanently lubricated sealed bearings.
2.13.7.5	Propellers and Motors	Propellers shall be dynamically balanced to ISO 1940/1-1986, G6.3, G2.5, or G1.0 as specified.
2.13.8.2	Fan and Drive Assembly	Fan and Rotating elements shall be statically and dynamically balanced to ISO 1940/1-1986, G6.3,.G2.5, or G1.0 as specified.
2.15	Air Handling Units (Factory Assembled)	Fan wheels shall be statically and dynamically balanced to ISO 1940/1-1986, G6.3, G2.5, or G1.0 as specified.
3.9	Air-Handling Systems Testing	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.10	Refrigeration Systems Testing	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.11	Air And Hydronic Systems Testing, And Adjustment	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.12	Steam And Condensate Systems Testing	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.13.1	Alignment	Added section to provide alignment directions and specifications.
3.13.2	Vibration Analyzer	Added section to provide vibration analyzer specifications.
3.13.3	Acceptance Tests	Added section to provide acceptance test requirements.
3.13.4	Test Records	Final test reports shall be provided to the Contracting Officer and forwarded to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.

Clause	Title	General RCM Application
15720	Air Handling Units	
1.2	General Requirements	Fan and motor balance shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted.
2.1	Air Handling Unit	AHU fan and motor shall be balanced to ISO 1940/1-1986, G6.3, G2.5, or G1.0 as specified.
3.2	Vibration Analyzer	Added section to provide vibration analyzer specifications.
3.3	Acceptance Tests	Added section to provide acceptance test requirements.
3.4	AHU TESTING	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15725	Air Handling	
2.1	General Fan Requirements	Fan and motor balance shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted.
2.1.1	General	Dynamically balance at the factory to ISO 1940/1-1986, G6.3, G2.5 or G1.0 as specified.
2.1.2	Bearings	When possible the use of sealed bearings is encouraged. Bearings shall have a certified AFBMA 9 or AFBMA 11, L-10 minimum life expectancy rating of 30,000, 40,000, 50,000, 80,000 hours as specified under load conditions the service will impose.
2.3.3	Fan Wheel	Wheel shall be statically and dynamically balanced to ISO 1940/1-1986, G6,3, G2.5, or G1.0.
2.3.4		
2.3.5		
2.4.3	Fan Wheel	Wheel shall be statically and dynamically balanced to ISO 1940/1-1986, G6,3, G2.5, or G1.0 as specified.
2.5.3	Fan Wheel	Wheels shall be statically and dynamically balanced to ISO 1940/1-1986, G6,3, G2.5, or G1.0 as specified.
3.2	Vibration Analyzer	Added section to provide vibration analyzer specifications.
3.3	Acceptance	Added section to provide acceptance test requirements.
15736	Computer Room Air Conditioning Units	
2.1	General	Fan and motor balance shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted.
2.10	Compressors	Compressor[s] shall be balanced to ISO 1940/1-1986, G6,3, G2.5 or G1.0 as specified.
3.5.1	Vibration Analyzer	Added section to provide vibration analyzer specifications.

Clause	Title	General RCM Application
3.5.2	Acceptance	Added section to provide acceptance test requirements.
15740	Heat Pumps	
2.2.3	Electrical Requirements	All motors shall have copper windings, be equipped with heavy duty ball bearings sealed permanently lubricated bearings.
3.4	Insulation	Insulation shall not impede access to duct covers/doors used for duct cleaning and/or maintenance.
3.7	Tests	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15762	Air Coils	
3.2	Tests	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database."
15764	Fan-coil Units	
2.1	General	Fan and motor balance shall conform to ISO Std. 1940/1 - (1986) Balance Quality Requirements of Rigid Rotors - Determination of Permissible Residual Unbalance unless otherwise noted. Motor vibration levels shall conform to NEMA Specification MG-1, Motors and Generators, Part 7 unless otherwise noted. NOTE: When possible the use of sealed bearings is encouraged.
2.4	Fan	Fan shall be balanced dynamically and statically to ISO Std. 1940/1 at the factory, after assembly in unit.
3.3		
3.4		
15766	Unit Heaters	
1.1		
1.3		
2	Products	When possible the use of sealed bearings is encouraged. Provides fan and motor balance and vibration level specifications.
15838	Power Ventilators	
2.3	Fan Type(s)	When possible the use of sealed bearings is encouraged.
2.5	Fan Motor	When possible the use of sealed bearings is encouraged.
3.3	Acceptance	Added section to provide acceptance test requirements.

Clause	Title	General RCM Application
3.3	Lubrication	Movable parts of dampers and related operating hardware shall be lubricated in accordance with manufacturer's printed instructions and shall operate smoothly and quietly without binding.
3.4	Final Test Reports	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
15902	Control systems	
2.8.2	Bearings	When possible the use of sealed bearings is encouraged.
2.11	Individual System Control Panels	Ability to open and/or remove access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
3.5	Testing, Calibration, and Acceptance	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.8		
15950	Testing and Balancing	
3	Execution	The Systems Engineer/Condition Monitoring Office/Predictive Testing Group should inspect the installation during acceptance testing using advanced monitoring technologies such as Infrared Imaging or Ultrasonic Listening.
3.3.7		
3.7	Test Reports	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
Division XVI	Electrical	
16003	General Electrical Provisions	
1.7	Prevention Of Corrosion	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings." Metallic materials shall be protected against corrosion. Equipment enclosures shall be given a rust-inhibiting treatment and the standard finish by the manufacturer when used for most indoor installations.
2.5	Painting	Refer to Section 09960, "High Performance Coatings," for requirements outdoors or in harsh environments.
16050	Basic Electrical Materials and Methods	

Clause	Title	General RCM Application
1.3	Prevention Of Corrosion	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings." Metallic materials shall be protected against corrosion. Equipment enclosures shall have the standard finish by the manufacturer when used for most indoor installations.
3.7	Panelboards	Ability to remove access covers is required for maintenance activities. No equipment shall be mounted within 36 inches of the front of the panel.
3.8	Dry-Type Distribution Transformers	Ability to remove access covers is required for maintenance activities. Minimum distances to energized circuits is specified.
3.10	Painting	Section 09960, "High Performance Coatings" was added to the specifications.
3.11	Field Testing	Adds final acceptance wire, cable and transformer inspection specifications. Final test data shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16124	Medium Voltage Cables	
2.4	Multiple-Conductor Shielded Cables	Cross-linked polyethylene insulation has been shown to tree when installed in wet environments. Also added additional cables to recommended list.
3.2	Field Testing	Added testing specifications including radiographic tests of potheads at the discretion of the Contracting Officer. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/ Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16125	Motors	
1.3	Submittals	Data for electric motors rated over 20hp and those specified to meet a special vibration class in accordance with NEMA MG 1 indicate number of: Rotor Bars, Stator Slots, rotational Speed, Cooling Fan Blades Bearing Manufacturer, Bearing Style, Bearing Type, Balls/Elements, Commutator Bars, Communtator Brushes Firing Frequencies (for variable speed motors).
2.1	Equipment	Design, fabrication, testing, and performance of motors shall be in accordance with NEMA MG 1 and ISO 1940/1. Testing and performance of polyphase induction motors shall be in accordance with IEEE Std 112, Method B. Efficiency labeling shall be in accordance with NEMA MG 1. Allowable vibration limits shall be in accordance with ISO 1940/1, Table 1.
3.2	Site Testing	Added additional testing specifications and that final test data shall be forwarded to the responsible systems engineer for inclusion in the Predictive Maintenance Program/ Database.
16275	Transformers	
1.3	Submittals	Test Report submittals for the following test were added: Power Factor Tests, Insulation Resistance Tests, and Insulation Power Factor(Doble) Tests.

Clause	Title	General RCM Application
1.4	Qualification Testing	Transformer manufacturer's standard tests were expanded to include; insulation power factor (Doble) tests, insulation oil tests, and dielectric tests. For oil-filled units manufacturer shall certify that the oil contains no PCB's and shall affix a label to that effect on the transformer tank and on each oil drum containing the insulating oil.
2.2	Factory Finish	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.2	Field Testing	For transformers rated under 100KVA and less than 4160 Volts on both primary and secondaries power factor testing is an optional acceptance test. Transformers shall be tested in accordance with IEEE Std. 62.
3.2.1.1	Dielelectric Tests	Liquid filled transformers shall have the insulating liquid dielectrically tested after installation and before being energized. Insulating liquid shall be tested in accordance with ASTM D 877, and breakdown voltage shall be not less than 2, 5, or 8,000 volts as specified.
3.2.1.2	Power Factor Tests	Liquid filled transformers shall have the oil power factored at 20 degrees C, per ASTM D 924 prior to being energized. Results shall not be greater than 0.5 percent at 20 degrees C.
3.2.2	Insulation-Resistance Tests	Added additional test specifications
3.2.3	Insulation Power Factor (Doble) Tests	Transformer windings shall be given an insulation power factor test and winding excitation test in accordance with ANSI IEEE C57.12.90. Insulation power factor shall not exceed 0.5 percent for new liquid filled units. New dry type units can have power factors up to 5.0 percent and still be acceptable.
3.2.4	Acceptance	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16276	Medium Voltage Transformers	
1.4	Qualification Testing	Added oil condition (acidity, water, power factor, dissolved gas, and dielectric), and the insulation power factor test (Doble Test). Maximum acceptable insulation power factor test value is 5 percent. Tests shall be conducted in accordance with IEEE C57.12.90, IEEE Std. 62, ASTM D 3612, and ASTM D 3487. Manufacturer shall certify that insulating oil contains no PCB's and shall affix a label to that effect on the transformer tank and on each oil drum containing the insulating oil.
2.8	Coils	For transformers to be installed in high fault current areas aluminum and sheet windings should be avoided.

Clause	Title	General RCM Application
2.11	Insulating Oil	Neutralization Number shall not be greater than .03 gm KOH/ml when measured in accordance with ASTM D 974. Emulsified water shall not exceed 25ppm at 20 degrees C. When measured in accordance with ASTM D 1533. Power factor shall not exceed .5 percent at 20 degrees C when measured in accordance with ASTM D 924.
2.13	Painting	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings." After fabrication, all exposed ferrous metal surfaces of the transformer and component equipment shall be cleaned and painted.
3.2	Field Testing	Upon satisfactory completion of the insulation resistance test the transformer windings shall be given an insulation power factor test and an excitation test. Added oil tests to be performed after electrical tests of the transformer. Transformer shall not be energized until recorded test data have been approved by the Contracting Officer. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16285	Medium Voltage Power Factor Correction	
1.2	Submittals	Added report on Capacitance Value Tests.
2.4	Prevention of Corrosion	Section on corrosion prevention (painting) of capacitor equipment was added.
3.2	Field Testing	Additional high-voltage capacitor equipment test specifications were added. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16286	Overcurrent Protective Devices	
1.2	Submittals	Factory Test Reports shall be submitted for Power, High Voltage, and Oil Circuit Breakers in accordance with ANSI C37.09 and shall include the following: Dielectric Tests, Bushing Tests, Insulating Oil Tests, Timing Tests, and Insulation Power Factor tests.
2.4.5	Oil Circuit Breakers	Oil for oil circuit breakers shall conform to ASTM D 3487. Oil circuit breakers shall be factory tested in accordance with ANSI C37.09.
2.12	Finish	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.2	Field Testing	Additional equipment test specifications were added. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16325	Load Break Switches	
3.1	Installation	Final switch acceptance specifications were added.
16326	Air-Break Switches	

Clause	Title	General RCM Application
3.1	Installation	Final switch acceptance specifications were added.
16327	Oil Switches	
2.2	Accessories	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.3	Field Testing	Load break switch assembly insulation-resistance test was changed from 2500V to 5000V.
3.4	Inspection	Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16328	Load Break SF6 Gas Switches	
2.6	Factory Finish	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.3	Field Testing	Provides additional field test specifications. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16345	Motor Control	
2.3	Construction	Access is required to inspect the motor control center while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
3.2	Field Testing	Provides additional field test specifications. Final test reports shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16365	Primary Unit Substation	
1.3	Submittals	Power Transformers, Transformer Tanks, Bushings, Transformer Cores, and Transformer Coils were added to Manufacturer's Catalog Data requirements. Power Transformers, Transformer Tanks, Bushings, Transformer Cores, and Transformer Coils were added to fabrication drawings to be submitted. The following were added to test reports : Insulation Power Factor Tests, Oil Power Factor Tests, Oil Acidity Tests, Water-in-oil (Karl Fischer) Tests, Dissolved Gas Analysis, Sound Tests, Impulse Tests, Short Circuit Tests, and Bushing Tests.
2.1	Equipment Standards	ANSI C37.121 was added to standards.

Clause	Title	General RCM Application
2.4.1	Transformers	For transformers to be installed in high fault current areas aluminum and sheet windings should be avoided. Transformer oil neutralization Number shall not be greater than .03 gm KOH/ml when measured in accordance with ASTM D 974. Emulsified water shall not exceed 25 ppm at 20 degrees C, when measured in accordance with ASTM D 1533. Power factor shall not exceed 0.5 percent at 20 degrees C when measured in accordance with ASTM D 924. The manufacturer shall certify that the oil contains no PCB's and shall affix a label to that effect on the transformer tank and on each oil drum containing the insulating oil.
2.5.1	Switchgear And Auxiliary Equipment Compartments	Ability to remove access covers is required for maintenance activities. In addition, access may be required to inspect these devices while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
2.11		
2.11.2	Shop Finishing	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.2	Field Testing	The following transformer tests were added: Insulation Power Factor Tests_Winding Excitation Tests Insulating Oil Tests Transformer windings and the main bus of primary-unit substations shall be subjected to insulation-resistance and insulation power factor test.
16366	Secondary Unit Substation	
2.3.1	Switchgear and Auxiliary Equipment Compartments	Ability to open access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
2.4.1	Transformers, Outdoor	Added the following to transformer oil specifications: Neutralization Number shall not be greater than .03 gm KOH/ml when measured in accordance with ASTM D 974. Emulsified water shall not exceed 25 ppm at 20 degrees C, when measured in accordance with ASTM D 1533. Power factor shall not exceed 0.5 percent at 20 degrees C when measured in accordance with ASTM D 924.
2.5.1	Switchgear and Auxiliary Equipment Compartments	Ability to open access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
2.6.3		
2.12	Painting	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."

Clause	Title	General RCM Application
3.1		
3.2	Field Testing	A number of transformer tests were added Final test data shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
16445	Switchgear Assemblies	
1.6.1		
2.2.1	Switchgear and Auxiliary Compartments	Ability to remove access covers is required for maintenance activities. In addition, access may be required to inspect this device while circuits are energized (for example, using infrared imaging). Minimum distances to energized circuits is specified in OSHA Standards Part 1910.333 (Electrical - Safety-Related work practices).
2.5	Painting	For all outdoor applications and all indoor applications in a harsh environment refer to Section 09960, "High Performance Coatings."
3.2	Field Testing	Final test data shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.
3.5	Energizing Switchgear Assemblies	Final test data shall be provided to the Contracting Officer for forwarding to the Systems Engineer/Condition Monitoring Office/Predictive Testing Group for inclusion in the Maintenance Database.

Appendix E - Glossary[17]

Note: The following are terms that are widely used in the Reliability Centered Maintenance philosophy and methodologies. Because of the likelihood that the reader will encounter the terms while doing Reliability Centered Acceptance, they are listed as a ready reference for better understanding. Additional terms and explanations can be found in the *NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment*.

Acceleration - The time rate of change of velocity. Typical units are ft/sec^2 and g's (1 g = 32.17 ft/sec^2 = 386 in/sec^2 = 9.81 meter/sec^2). Acceleration measurements are made with accelerometers.

Accelerometer - Transducer where the output is directly proportional to acceleration. Most commonly used are mass loaded piezoelectric crystals to produce an output proportional to acceleration.

Accessible- The ability to fully reach, adjust and maintain the equipment. Consideration should be given to confined space restrictions, removing guards, bushing plates, hydraulic lines, lubrication lines, electric lines etc. Also, on a broader scale, the ability to gain access to the equipment due to security, safety and other restrictions.

Age Exploration - The process of determining the most effective intervals for maintenance tasks. Its called age exploration because it is often associated with identifying age related maintenance actions such as overhaul and discard tasks and then extending the interval between tasks.

Alignment Target Specifications - Desired intentional offset and angularity at coupling center to compensate for thermal growth and/or dynamic loads. Most properly specified as an OFFSET, and an angle in two perpendicular planes, horizontal and vertical.

Amplitude - A measure of the severity of vibration. Amplitude is expressed in terms of peak-to-peak, zero-to-peak (peak), or rms. For pure sine waves only:

- Peak (P) = 1.414 x RMS
- Peak-to-Peak = 2 x Zero-to-Peak (Peak)

Amplitude Limits - The total vibration level "A" in a band, as defined by the following equation, shall not exceed the Overall Amplitude Acceptance Limit specified for the Band

A	=	Overall vibration level in the Band
Ai	=	Amplitude in the ith line of resolution in the Band
(i = 1)	=	The first line of resolution in the Band
(i=N)	=	The last line of resolution in the Band
N	=	The number of lines of resolution in the Band

[17] The reference for many of the definitions in this Glossary is the Glossary from Hewlett Packard's Publication *Effective Machinery Measurements Using Dynamic Signal Analyzers*, Application Note 243.1.

W = Window Factor (W = 1.5 for a Hanning Window)

Angular Error - A misalignment condition characterized by the angular error between the desired centerline and the actual centerline. This misalignment condition may exist in planes both horizontal and vertical to the axis of rotation.

Angularity - The angle between the rotational centerlines of two shafts. Angularity is a "slope" expressed in terms of a rise (millimeters or thousandths of an inch) over a run (meter or inches).

Anti-Aliasing Filter - A low-pass filter designed to filter out frequencies higher than 1/2 the sample rate in order to prevent aliasing.

Availability - (1) Informally, the time a machine or system is available for use. (2) From the Overall Equipment Effectiveness calculation, the actual run time of a machine or system divided by the scheduled run time. Note that Availability differs slightly from Asset Utilization (Uptime) in that scheduled run time varies between facilities and is changed by factors such as scheduled maintenance actions, logistics, or administrative delays.

Axial Play - Shaft axial movement along its centerline caused by axial forces, thermal expansion or contraction, and permitted by journal bearings, sleeve bearings and/or looseness. Also Axial Float, End Float.

Balance - When the mass center line and rotational center line of a rotor are coincident.

Balancing - A procedure for adjusting the radial mass distribution of a rotor by adding or removing weight, so that the mass centerline approaches the rotor geometric centerline achieving less vibration amplitude at rotational speed.

Band-Limited Overall Amplitude - For vibration level limits specified in terms of "Band-Limited Overall Reading."

Band Limited Overall Reading - The vibration severity amplitude measured over a frequency range defined by a F_{MIN} and a $F_{MAX.}$

Beats - Periodic variations in the amplitude of an oscillation resulting from the combination of two oscillations of slightly different frequencies. The beats occur at the difference frequency. ISO 2041 (1990).

Beat Frequency - The absolute value of the difference in frequency of two oscillations of slightly different frequencies. ISO 2041 (1990)

Blade Pass Frequency - A potential vibration frequency on any bladed machine (turbine, axial compressor, fan, pump, etc.). It is represented by the number of fan blades or pump vanes times shaft rotating frequency. Also Pumping Frequency.

Building Commissioning - The systematic process for achieving, verifying, and documenting that the performance of NASA Faculties and Collateral Equipment meets the design intent. The process extends through all phases of a project and culminates with occupancy and operation. The process includes the testing and accepting of new or repaired building, system or component parts to verify proper installation.

Calibration - A test to verify the accuracy of measurement instruments. For vibration, a transducer is subjected to a known motion, usually on a shaker table, and the output readings are verified or adjusted.

Co-Linear - Two lines that are positioned as if they were one line. Co-linear as used in alignment means two or more centerlines of rotation with no offset or angularity between them. Two or more lines are co-linear when there is no offset or angularity between them (i.e. they follow the same path).

Complete Machine - A complete machine is defined as the entire assembly of components, sub-components, and structure, which is purchased to perform a specific task(s). On a Complete Machine Assembly with all individual components operating in their normal operating condition, mode, and sequence, the Component Vibration Level Limits for the complete machine acceptance are the same as when the component is tested individually.

Coplanar - The condition of two or more surfaces having all elements in one plane. (per ANSI Y14.5)

Cost Effective - An economic determination of the Maintenance Approach and entails the evaluation of maintenance costs, support costs, and consequences of failure.

Coupling Point - The phrase "COUPLING POINT" in the definition of SHAFT ALIGNMENT is an acknowledgment that vibration due to misalignment originates at a the point of power transmission, the coupling. The shafts are being aligned and the coupling center is just the measuring point.

Critical Failure - A failure involving a loss of function or secondary damage that could have a direct adverse effect on operating safety, on mission, or have significant economic impact.

Critical Failure Mode - A failure mode that has significant mission, safety or maintenance effects that warrant the selection of maintenance tasks to prevent the critical failure mode from occurring.

Critical Speed - The speed of a rotating system corresponding to a system resonance frequency.

Decibel (Db) - A logarithmic representation of amplitude ratio, defined as 20 times the base ten logarithm of the ratio of the measured amplitude to a reference. dBV readings, for example, are referenced to 1 volt rms. dB amplitude scales are required to display the full dynamic range of an F Analyzer.

Displacement - The distance traveled by a vibrating object. For purposes of this document, displacement represents the total distance traveled by a vibrating part or surface from the maximum position of travel in one direction to the maximum position of travel in the opposite direction (Peak-to-Peak) and is measured in the unit mil (1 mil = 0.001 inch).

Dominant Failure Mode - A single failure mode that accounts for a significant portion of the failures of a complex item.

Dynamic Mass - To determine if the mass of the transducer is effecting the measurement, perform the following steps:

(a) Make the desired measurement with the accelerometer.
(b) Place a mass equivalent to the mass of the accelerometer adjacent to the measuring accelerometer.
(c) Repeat the measurement.
(d) Compare data from (a) and (c)
(e) If any differences (i.e. shift in frequencies) between (a) and (c) exist, then a less massive transducer should be used in a.

Dynamic Range - The difference between the highest measurable signal level and the lowest measurable signal level that is detectable for a given Amplitude Range setting. Dynamic Range is usually expressed in decibels, typically 60 to 90 dB for modern instruments.

Failure - A cessation of proper function or performance; the inability to meet a standard; nonperformance of what is requested or expected.

Failure Effect - The consequences of failure.

Failure Mode - The manner of failure. For example, the motor stops is the failure - the reason the motor failed was the motor bearing seized which, is the failure mode.

Failure Modes and Effects Analysis (FMEA) - Analysis used to determine what parts fail, why they usually fail, and what effect their failure has on the systems in total.

FFT (Fast Fourier Transform) - A calculation procedure which converts a time domain signal into a frequency domain display.

FFT Analyzer - Vibration analyzer that uses the Fast Fourier Transform to display vibration frequency components.

F_{MAX} - Maximum Frequency Limit of the spectrum being evaluated.

F_{min} - Minimum Frequency Limit of the spectrum being evaluated.

Frequency - The repetition rate of a periodic event, usually expressed in cycles per second (Hertz -abr. HZ), cycles per minute (CPM), or multiples of rotational speed (Orders). Orders are commonly referred to as IX for rotational speed, 2X for twice rotational speed, etc. Frequency is the reciprocal of the Period.

> **NOTE:** Vibration frequencies are expressed in Hertz (cycle per sec) or CPM (cycle per minute). Rotational speed (Running Speed) is expressed in RPM (Revolutions per minute).

Frequency Domain - Presentation of a signal whose amplitude is measured on the Y axis, and the frequency is measured on the X-axis.

Frequency Resolution (ΔF) - Δ f = (FMAX - FMIN)/# Lines of resolution. Δf represents the minimum spacing between data points in the spectrum.

Frequency Response - Portion of the frequency spectrum that can be covered within specified frequency limits.

Function - A defined performance standard. Usually quantitative in nature (flow rate, cooling capacity, etc.).

Gear Mesh Frequency - A potential vibration frequency on any machine that contains gears: equal to the number of teeth multiplied by the rotational frequency of the gear.

Hanning Window - A Digital Signal Analysis (DSA) window function that provides better frequency resolution than the flat top window, but with reduced amplitude

Harmonic - Frequency component at a frequency that is an integer (whole number e.g. 2X. 3X. 4X, etc.) multiple of the fundamental (reference) frequency.

Hertz (Hz) - The unit of frequency represented by cycles per second.

Hi Bandpass Filter - A device that separates the components of a signal and allows only those components above a selected frequency to be amplified.

Horizontal - Parallel to the mounting surface.

Imbalance - Unequal radial weight distribution of a rotor system; a shaft condition such that the mass and shaft geometric centerlines do not coincide.

Inspection - A time- or cycle-based action performed to identify hidden failure or potential failure.

Infrared Thermography - A predictive technique that uses infrared imaging to identify defects in electrical and electro-mechanical devices such as fuse boxes, circuit breakers, and switchgear. It also can be used effectively in a non-predictive manner to detect thermal cavities and leaks in walls, ceilings, and rooftops, the correction of which can result in sizeable reductions in heating and air conditioning expenses. Thermal imaging is extremely sensitive, and since it evaluates the heat an object emits, emittance and reflective factors of the object and environment must be considered.

Jackbolts, Jackscrews - Positioning bolts on the machine base that are located at each foot of the machine and are used to adjust the position of the machines.

Large Apparatus AC/DC Motors - Reference NEMA Publication No. MG 1, Motors and Generators, Section III

Level - Parallel to a reference plane or a reference line established by a laser.

Line Amplitude Limit - The maximum amplitude of any line of resolution contained within a band shall not exceed the Line Amplitude Acceptance Limit for the Band.

Linear Non-Overlapping Average - An averaging process where each Time block sample used in the averaging process contains data not contained in other Time blocks (i.e. Non-overlapping) used in the averaging. Linear averaging is performed in the Frequency Domain, and each sample is weighted equally.

Line Of Resolution - A single data point from a spectrum which contains vibration amplitude information. The Line of Resolution amplitude is the Band Overall Amplitude of the frequencies contained in the Δf Frequency Resolution.

Machine - The total entity made up of individual machine components such as motors, pumps, spindles, fixtures, etc. Also see Machine Component.

Machine Base - The structure that supports the machine or machine components under consideration.

Machine Component - An individual unit such as a motor, pump, spindle, fixture, etc. often referred to as a machine in its own context.

Maintainability - The ability to retain or restore function within a specified period of time, when provided with an identified level of tools, training, and procedures. Maintainability factors include machine and systems access, visibility, simplicity, ease of monitoring or testing, special training requirements, special tools, and capability of local work force

Maintenance - Action taken to retain function (i.e., prevent failure). Actions include Preventive Maintenance, Predictive Testing & Inspection, lubrication and minor repair (such as replacing belts and filters), and inspection for failure. Also see Preventive Maintenance and Predictive Testing & Inspection.

Measurement Point - A location on a machine or component at which vibration measurements are made.

Micrometer (Micron) - One millionth (0.000001) of a meter. (1 micron = 1 x 10^{-6} meters = 0.04 mils.)

MIL - One thousandth (0.001) of an inch. (1 mil = 25.4 microns.)

Motor Circuit Analysis (MCA) - A predictive technique whereby the static characteristics (i.e.; impedance, capacitance to ground, inductance) of a motor or generator are measured as indicators of equipment condition.

Motor Current Spectrum Analysis (MCSA) - A predictive technique whereby motor current signatures provide information on the electro-mechanical condition of AC induction motors. It detects faults such as broken rotor bars, high resistance joints, and cracked rotor end rings by collecting motor current spectrums with clamp-on sensors and analyzing the data.

Natural Frequency - The frequency of free vibration of a system when excited with an impact force. (Bump Test).

Offset - The distance (in thousands of an inch or in millimeters) between the rotational centerlines of two parallel shafts.

Order - A unit of frequency unique to rotating machinery where the first order is equal to rotational speed. See FREQUENCY

Peak - Refers to the maximum of the units being measured, i.e., peak velocity, peak acceleration, peak displacement.

Peak-To-Peak - Refers to the displacement from one travel extreme to the other travel extreme. In English units, this is measured in mils (.001 inch) and in metric units it is expressed in micro-meter μM (.000001 meters).

Period - The amount of time, usually expressed in seconds or minutes, required to complete one cycle of motion of a vibrating machine or machine part. The reciprocal of the period is the frequency of vibration.

Phase (Phase Angle) - The relative position, measured in degrees, of a vibrating part at any instant in time to a fixed point or another vibrating part. The Phase Angle (usually in degrees) is the angle between the instantaneous position of a vibrating part and the reference position. It represents the portion of the vibration cycle through which the part has moved relative to the reference position .

Pitch - An angular misalignment in the vertical plane. (ANSI/ASME b5.54-1991)

Position Error (Centerline/Offset Misalignment) - A misalignment condition that exist when the shaft centerline is parallel but not in line with (not coincidental) with the desired alignment centerline.

Potential Failure - An identifiable condition that indicates a failure is imminent.

Predictive Testing & Inspection (PT&I) - The use of advanced technology to assess machinery condition. The PT&I data obtained allows for planning and scheduling preventive maintenance or repairs in advance of failure. Also known as Condition Monitoring, Predictive Maintenance and Condition-Based Maintenance.

Preventive Maintenance - Time- or cycle-based actions performed to prevent failure, monitor condition, or inspect for failure.

Predictive Maintenance - See Predictive Testing and Inspection (PT&I).

Proactive Maintenance - The collection of efforts to identify, monitor and control future failure with an emphasis on the understanding and elimination of the cause of failure. Proactive maintenance activities include the development of design specifications to incorporated maintenance lessons learned and to ensure future maintainability and supportability, the development of repair specifications to eliminate underlining causes of failure, and performing root cause failure analysis to understand why in-service systems failed.

Radial Measurement - Measurements taken perpendicular to the axis of rotation.

Radial Vibration - Shaft dynamic motion or casing vibration which is in a direction perpendicular to the shaft centerline.

Reliability - The dependability constituent or dependability characteristic of design. From MIL-STC-721C: Reliability - (1) The duration or probability of failure-free performance under stated conditions. (2) The probability that an item can perform its intended function for a specified interval under stated conditions.

Reliability-Centered Maintenance (RCM) - The process that is used to determine the most effective approach to maintenance. It involves identifying actions that, when taken, will reduce the probability of failure and which are the most cost effective. It seeks the optimal mix of Condition-Based Actions, other Time- or Cycle-Based actions, or Run-to-Failure approach.

Repair - That facility work required to restore a facility or component thereof, including collateral equipment, to a condition substantially equivalent to its originally intended and designed capacity, efficiency, or capability. It includes the substantially equivalent replacements of utility systems and collateral equipment necessitated by incipient or actual breakdown. Also, the restoration of function, usually after failure.

Repeatability - The consistency of readings and results between consecutive sets of measurements.

Resonance - The condition of vibration amplitude and phase change response caused by a corresponding system sensitivity to a particular forcing frequency. A resonance is typically identified by a substantial amplitude increase and related phase shift.

Rolling Element Bearing - Bearing whose low friction qualities derive from rolling elements (balls or rollers), with little lubrication.

Root Cause Failure Analysis (RCFA) - The process of exploring, in increasing detail, all possible causes related to a machine failure. Failure causes are grouped into general categories for further analysis. For example, causes can be related to machinery, people, methods, materials, policies, environment, and measurement error.

Rotational Speed - The number of times an object completes one complete revolution per unit of time, e.g., 1800 RPM.

Shaft Alignment - Positioning two or more machines (e.g. a motor driving a hydraulic pump(s), etc.) so that the rotational centerlines of their shafts are collinear at the coupling center under operating conditions.

Side Band - Equals the frequency of interest plus or minus one times the frequency of the exciting force.

Signature (Spectrum) - Term usually applied to the vibration frequency spectrum which is distinctive and special to a machine or component, system or subsystem at a specific point in time, under specific machine operating conditions, etc.

Usually presented as a plot of vibration amplitude (displacement, velocity or acceleration) versus time or versus frequency. When the amplitude is plotted against time it is usually referred to as the TIME WAVE FORM.

Small (Fractional) And Medium (Integral) Horsepower AC/DC Motors - Reference NEMA Publication No. MG 1, Section II SMALL (FRACTIONAL) AND MEDIUM (INTEGRAL) MACHINES. Part 12. Tests and Performance - AC and DC Motors.

Soft Foot - A condition that exists when the bottom of all of the feet of the machinery components are not on the same plane (can be compared to a chair with one short leg). Soft foot is present if the machine frame distorts when a foot bolt is loosened or tightened. It must be corrected before the machine is actually aligned.

Stress Free Condition - The condition that exists when there are no forces acting on the structure of a machine, machine component, or machine base that would cause distortion in the structure such as bending, twist, etc.

Thermal Effects (Growth Or Shrinkage) - This term is used to describe displacement of shaft axes due to machinery temperature changes (or dynamic loading effects) during start-up.

Time- or Cycle-Based Actions - Maintenance activities performed from time-to-time that have proven to be effective in preventing failure. Items such as lubrication and restoration of wear fit this description. Other items that are Time- or Cycle-Based are inspection and condition monitoring. Also see Predictive Testing and Inspection.

Time Domain - Presentation of a signal whose amplitude is measured on the Y axis and the time period is measured on the X axis.

Tolerance - An area where all misalignment forces sum to a negligible amount and no further improvement in alignment will reduce significantly the vibration of the machine or improve efficiency. Also Deadband, Window or Envelope.

Tolerance Values - Maximum allowable deviation from the desired values, whether such values are zero or non-zero.

Transducer (Pickup) -Vibration - A device that converts shock or vibratory motion into an electrical signal that is proportional to a parameter of the vibration measured. Transducer selection is related to the frequencies of vibration which are important to the analysis of the specific machine(s) being evaluated/analyzed.

Unbalance - See IMBALANCE

Velocity - The time rate of change of displacement with respect to some reference position. For purposes of this document, velocity is measured in the units Inch per second-Peak.

Vertical - Perpendicular to the horizontal plane.

Vibration Analysis— The dominant technique used in predictive maintenance. Uses noise or vibration created by mechanical equipment to determine the equipment's actual condition. Uses transducers to translate a vibration amplitude and frequency into electronic signals. When measurements of both amplitude and frequency are available, diagnostic methods can be used to determine both the magnitude of a problem and its probable cause. Vibration techniques most often used include broadband trending (looks at the overall machine condition), narrowband trending (looks at the condition of a specific component), and signature analysis (visual comparison of current versus normal condition). Vibration analysis most often reveals problems in machines involving mechanical imbalance, electrical imbalance, misalignment, looseness, and degenerative problems.

Yaw Misalignment - An angular misalignment in the horizontal plane.

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